Innovation Index Based Frame Work for Design of Products Manufactured by Small Scale Sectors in India

A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy
By

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DECLARATION

I hereby declare that the work contained in this thesis entitled **"Innovation index based frame work for design of products manufactured by small scale sectors in India"** is my own work and done under the guidance of Professor Pradeep Yammiyavar, at the Department of Design, and Dr. Vinayak Kulkarni of Mechanical Department, Indian Institute of Technology Guwahati, Assam. To the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at IIT Guwahati or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at IIT Guwahati or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is duly acknowledged.

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CERTIFICATE

This is to certify that the work contained in this thesis titled "**Innovation index based frame work for design of products manufactured by small scale sectors in India"** submitted by **Mr. Ravi Lingannavar** to the Indian Institute of Technology Guwahati for the award of the degree of Doctor of Philosophy has been carried out under my supervision. This work has not been submitted elsewhere for the award of any other degree.

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Ravi Lingannavar

Abstract

The contribution of Micro Small and Medium Enterprises (MSMEs) to the economy and employment market is growing. They are involved in manufacture of products that range from simple to complex in terms of engineering and design. However, it is widely known that MSMEs in India are slow in adopting innovation practices. MSMEs are slow in focusing on the need for innovation in line with current government initiative and policies that encourages as many products as possible to be made in India. However, it is observed that most small and medium enterprises have not developed inherent capacity for absorbing subsidies and funds earmarked for innovation by the Government nor do they have resources for practicing Innovation. As a result, MSMEs in India lag behind those in other Asian countries such as China, Singapore and Malaysia in embracing the practice of continuous innovation and benefit from it.

Initial studies on small enterprises conducted in the course of this research reveal that enterprises lack methods of incorporating innovation during the design upgradation phase in their product development process. Most medium scaled enterprises depend on vendor industries to give them designs along with job orders which they produce. They seem to be content at being ancillary to industries. They have not developed in-house Design capacity and capabilities. Reverse engineering is relied upon. Small enterprises and medium enterprises seem to be clueless as to how to innovate, how to generate new ideas and how to continuously improve their products' quality and variety. The research reported in this thesis aims to investigate the state of art as prevalent amongst MSMEs with respect to their practices and efforts to improve product quality and thereupon propose novel methods to measure and incorporate innovation through design which is specifically developed for the type of products manufactured by them.

This thesis reports the studies that have been done to answer the questions for MSMEs such as how to innovate effectively and quickly? Where to focus during product designing phase to enable value addition? What are the variables that influence innovation? How to measure innovation and metricize comparative benefits? How to compare competitive products for their innovative content?

This thesis proposes a new method involving a systematic series of steps and procedure to add value to products through Design so as to achieve innovation. The frame work proposed aims at locating specific components/subassembly/parts of a products' design wherein innovation, if done, would result in higher value addition to the overall product. A new human centered design based frame work for innovation was developed through product analysis, leading to improvements by generating new concepts, selecting the most promising concept by a metric frame work, based on linkographs.

The innovation frame work developed in this thesis is based on the principles of Usability engineering as contained in ISO (ISO 9241, ISO 13407) standards. Products manufactured by MSMEs are deconstructed using disassembly tools such as Fish bone diagram, Value analysis trees, Usability testing protocols, linkography and weighted matrices. In the method proposed in this thesis, prioritization of design elements was done from the user's 'usability' and products ‘utility’ point of view rather than solely on engineering, material or manufacturing point of view. The products chosen for experiments were utility consumer household products. The word ‘Design’ used here indicates Creative concept generation process as in User Centered Design and does not confine itself to ‘routine design’ process of machine elements. As such domain knowledge from multiple disciplines such as User centered product design, Mechanical Engineering, and Management Science (operations management) have been used in an interdisciplinary way throughout the thesis.

In order to validate the proposed frame work developed for innovation, professionally trained designer (30) were asked to redesign products with a new innovation framework. A matrix framework based on pre and post design action was developed. This developed framework was further validated by trials with ten (10) MSMEs who applied it to their existing products in a demonstration exercise for feedback. The framework aids analysis of similar product designs by identifying spots within the product assembly that can be innovated. The frame work aids in attaining higher innovation and helps in measuring the innovation improvement differential. This thesis is in Product Design, it encompasses, Mechanical engineering, User centric design, Usability Engineering, and Industrial policy aspects concerning small and medium scaled industrial enterprises.

The thesis argues that by knowing the innovation index between two comparable products and identifying the exact spots of innovation, MSMEs can practice, design through innovation. Validation by feedback from MSMEs indicated that the new method and frame work is easy to understand and implement within a small or medium enterprise.

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Abbreviations used in the thesis

AEF	Aesthetics, Ergonomics, Function
BM	Business model
BPR	Business process reengineering
CII	Confederation of Indian Industry
CIM	Computer integrated manufacturing
CM	Critical Moves
DFM	Design for manufacturing
DMADV	Define, Measure, Analyze, Design and Verify
DMAIC	Define, Measure, Analyze, Improve and control
DT	Design thinking
FBD	Fish bone diagram
FMS	Flexible manufacturing system
GDP	Gross domestic product
GII	Global innovation index
GT	Graph Theory
HCI	Human computer interaction
ICT	Information and communication technology
ISO	International Organization for Standardization
JIT	Just in time
MSME	Micro, Small and medium scale enterprises
NIRD	National Institute of Rural Development
NPD	New product development
PD	Product design
PDCA	Plan-Do-Check-Act (Deming circle)
PDM	Product Design and Manufacturing
QFD	Quality function Deployment
R&D	Research and development
ROI	Return on investment
SCAMPER	Substitute, Combine, Adapt, Modify, put to another use, eliminate and Reverse
SME	Small and medium scale enterprises
TQM	Total quality management
TRIZ	Teorita Ressheniya Izobretatelskikh zadach, [Theory of inventive problem solving]
UCD	User centered design
UPO	Usability, Processes, Operations
VA	Value analysis
VE	Value engineering
WCM	World class manufacturing

Chapter 1

1. Introduction

Abstract: The first chapter introduces the background and context in which the research reported in the subsequent chapters have been undertaken. It outlines the aims, objectives and purpose of the research. It describes the frame work around which the research plan is formulated. The overall methodology followed along with definitions of terms used have been outlined. Chapter-wise content description of the thesis is given.

1.1 Overview of innovation and design in Indian Micro, Small and Medium Enterprises (MSMEs)

The contribution of Micro Small and Medium Enterprises (MSMEs) to the Indian economy, has helped in the growth of the employment market. Since 2012, MSMEs have attracted a lot of attention and are the focus of government policies, such as Make in India, MSME tool rooms, Design clinics, Udyog Aadhaar Memorandum, National Manufacturing Competitiveness Programme, Digital Initiatives etc. [Annual report, MSME 2016-17] these are involved in manufacture of products that range from simple to complex in terms of engineering and design. Based on the reports of Skill development of MSME sector and Strategic Development of MSMEs, it can be inferred that the strategies, practices, methods, tools, techniques and skills need to be upgraded. MSMEs are slow in focusing on the need for innovation in-line with current government initiative and policy that encourages products to be made in India. It is observed by several published studies that most small and medium enterprises have not developed inherent capacity for absorbing subsidies and funds earmarked for innovation by the government, nor do they have resources for new product development [Annual report, MSME 2017]. Innovation does not seem to be practiced as expected. To continue making profits in the prevalent competitive marketing environment one needs to adopt these practices. As a result, the MSMEs in India are lagging in comparison to the Asian countries such as China, Singapore and Malaysia on many parameters. This issue has been discussed widely in the media and articles {Example - [Ghoshal. M, 2017]; [AUTO –ET, 2018] [Grant Thornton, 2018]; [SME TIMES, 2015]}.

Graphic information from INSEAD Global and The Economics Time as shown in Figs. 1.1 and 1.2. [The Economic Times, 23-07-2015] indicate that the MSMEs in India have a huge potential in uplifting innovation activity. The Global Innovation Index (GII) (Table 1.1) ranking of India is low in comparison to other countries. This indicates the need for focusing on innovation research. It can be observed in Fig. 1.1 that the percentage of GDP spending in R&D is very low in comparison with other countries. This can be attributed to low priority given to practice of innovation in Indian MSMEs in general. The need for designers to improve the Indian innovation indices in comparison to other countries inspired us to think of this research plan and come up with a simple yet effective method to cater to the needs of small and medium sectors. This gap of non-availability of in-house capacity on one hand and high potential for innovation on the other is proposed to be filled by the innovation framework developed in this thesis.

Table 1.1: Global Innovation Index

Rank In	2018	2017	2016	2015
Switzerland	1	1	1	1
United Kingdom	4	5	3	2
United States	6	4	4	5
Hong Kong	14	16	14	11
Israel	11	17	21	22
China	17	22	25	29
India	57	66	60	81

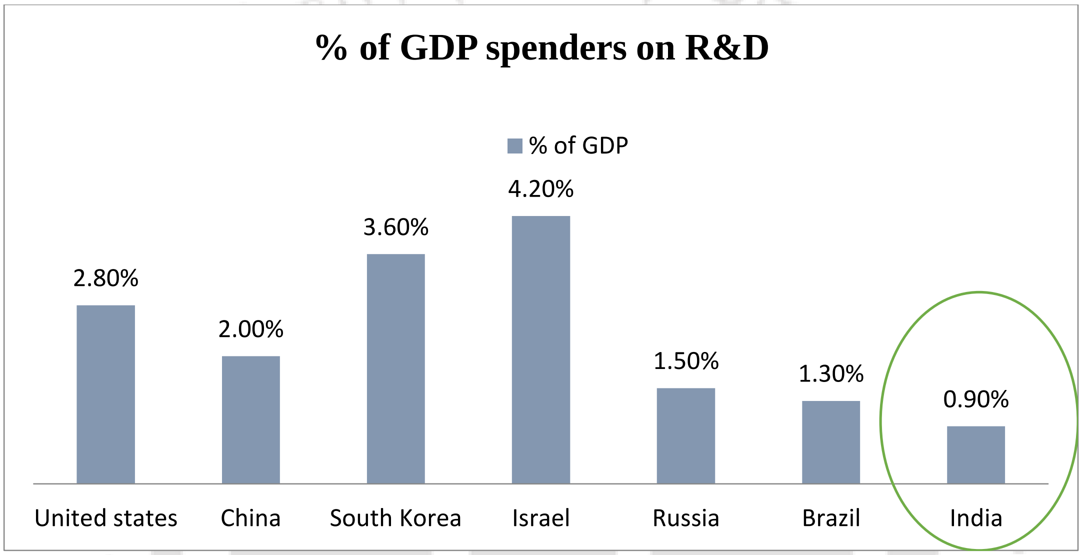


Figure 1.1: The percentage of GDP spenders on R&D

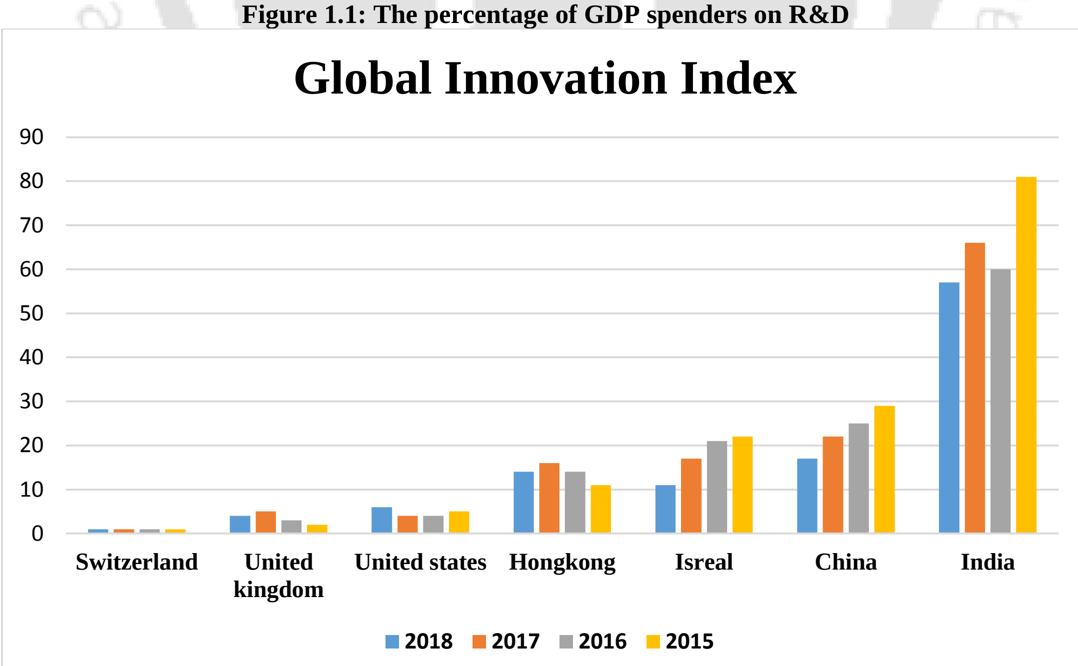


Figure 1.2: The comparison of rankings of global innovation index

The Table 1.2 [Arroio & Scerri, 2010] indicates the Government policy support to countries bracketed with India as far as MSMEs are concerned. In the past three years (2015 onwards) Indian Government is making up, by funding and encouraging innovation in all sectors of the industry.

Table 1.2: Different government policies of BRICS nations adopted and modified from Arroio & Scerri, [2010]

	SME policies	SME Innovation policies	Main support institution	Innovation finance	R&D Spending
Brazil	✓	Local Productive arrangements	SEBRAE	Funds for Innovation	1.2%
Russia	✓	Universities & industrial parks, innovation centers, industrial growth poles	Rosnauka	Funds for Innovation	1.2%
India	✓	MSMED Act 2006, clusters	Ministry of MSME	No	0.6%
China	✓	High tech zones, Incubators, S & T parks, industrial growth poles	Productivity promotion center	Separate Innovation Funds	2%
South Africa	✓	SDI, clusters, Technology stations	SEDA	Khula Enterprises finance	0.5

SEBRAE: *Serviço Brasileiro de Apoio às Micro e Pequenas Empresas - (Brazilian service of assistance to micro and small enterprises)* ***Rosnauka:*** *Federal Agency for Science and Innovations (Rosnauka)* ***MSME:*** *Ministry of Micro, Small & Medium Enterprises* ***SEDA****: Small Eneterprises Development Agency,*

The term 'Innovation' has many meanings depending on the context and perception of its use. It is used in a wide verity of contexts to describe anything new. Its frequency of use in popular media makes it a buzz word or a fashionable jargon. In design the term 'innovation' is an integral outcome of creative design thinking and problem solving. Innovation and design are concerned with the product as well as the designer who conceives the product with an intention of solving a real-world problem. For the engineers in MSMEs, innovating or creating new products through design does not seem to be a priority as they have limited access to resources for research and development (R&D). Many small enterprises concentrate on attempting to make reasonable profit in a fiercely competitive and price sensitive environment. Innovation is the last action point in their list of strategies. The small-scale enterprises are seldom motivated to change the status quo. They are in the comfort zone if the orders are on the books and their products are sold. Attention is given to a new design or an innovation only when a crisis looms, or their product becomes obsolete, either due to technology or due to competition or the user having drifted away. Their first kneejerk measure is to reduce their profit margins, use lower cost material or compromise on the quality. Seldom do they think of new product development and innovation as a possible option. Adding value to the existing product or creating an entirely new product with added features at lower cost is a herculean task beyond the time scale and capacity of a small-scale sector enterprises.

From the practices and state of affairs as discussed in publications and media articles, it is known that the MSMEs in India lack adequate tools, methods and processes that can assist them to practice innovation as part of the routine management of their enterprises. Most of the medium scale enterprises depend on vendor industries for their designs along with job orders which they produce. They have not developed in-house design capabilities and the most common practice followed is reverse engineering and it is practiced most of the time. Small enterprises and medium enterprises seem to be clueless regarding innovation, generation of new ideas and continuous improvement of their products. This thesis attempts to examine the possibility of understanding innovation practice from the MSMEs point of view and to evolve newer models and frameworks to assist small enterprises to practice innovation.

This thesis reports the studies that have been done to answer the question for MSMEs such as how to innovate? Where to focus in product designing phase to enable value addition? What are the variables that influence innovation? How to measure innovation and its benefits? How to compare competitive products for the added value? In this thesis an attempt has been made to develop, through research and experimental validation, a process for innovation that is suitable for Indian small and medium enterprises. The process proposes an Innovation metrics frame work and tool set for design of products specifically manufactured by MSMEs. The framework assists in comparative product analysis and pin pointing spots within the product that can benefit by innovation. This is done by using the linkographic analysis technique as part of Design Audit exercise. Using results of the Design audit, a designer or engineer can save time and effort to come up with creative strategy that ensures innovation either for an existing product as a whole or part thereof and which may even yield specification for a new category of products altogether. The Frame work proposed is capable of relatively indexing the innovation levels and state which of the two products under comparison have higher innovation quality content or value added especially from the user's (product usability) point of view. It also indicates in which part/area/assembly of the product it is or has the potential to be embedded. The framework proposed in this thesis also facilitates value addition through creative design sourced from User based usability and utility criteria.

The developed Frame work proposes an improved method involving a systematic series of steps and procedure to add value to products through design. Design in this context is w.r.t Industrial design or Product design, which employs Human centered approach. The Frame work can also be used as an Innovation morphology model which aims at locating specific components/ subassembly/parts of a product's design where in innovation- (improvement), if done, would ensure higher value addition.

1.2 Understanding Micro, Small and Medium Enterprises their contributions and limitations

MSME's in India contribute to industrial output, exports, employment and produce a large variety of products for both domestic and international markets with market value of ₹ 1,471,912.94 crores [Annual report, MSME 2015-16, evoma.com 2017]. Fig. 1.1 shows that in India, MSMEs contribute nearly 45% to manufacturing and 40% to the Indian export sector. Indian MSMEs have moved up the value chain from manufacture of simple goods to manufacture of sophisticated products. In-line with the overall growth of Indian economy, they have entered the services sector as well [CII report, 2011].

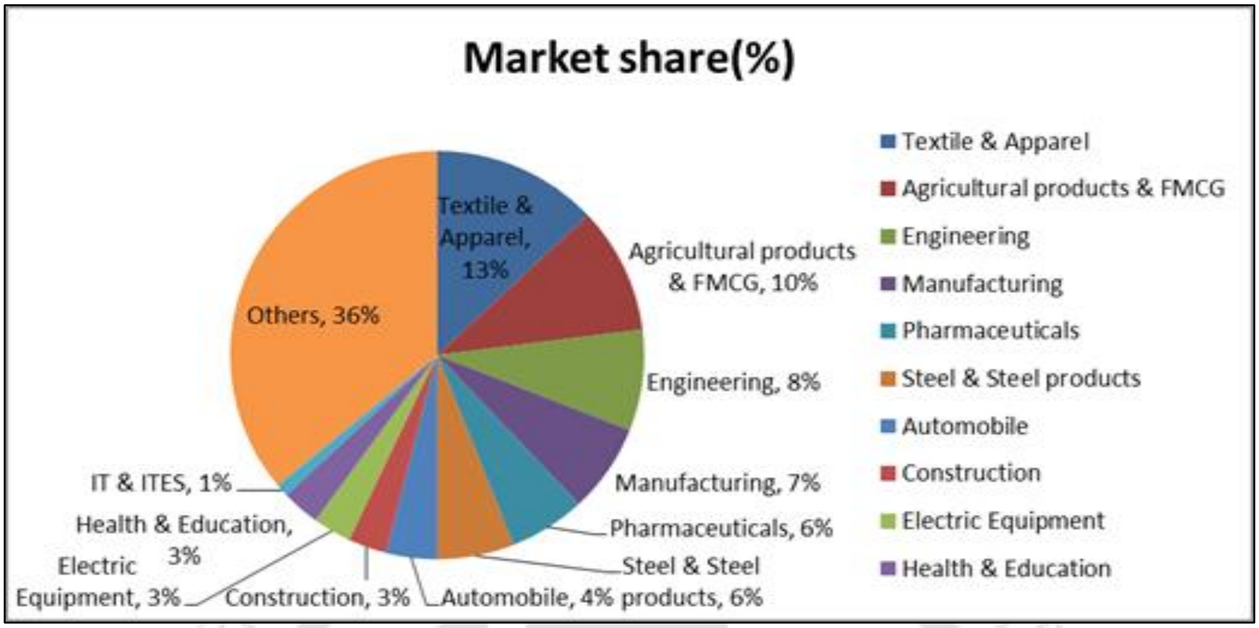


Figure 1.3: Total market share of MSMEs by sectors in India Adopted and redrawn, http://insideiim.com/

There are about twenty-one major industry groups in the small-scale sector by MSMEs. There are over 6000 products ranging from traditional to high-tech items, which are being manufactured by the MSME sector besides providing wide range of services percentage wise as shown in Fig. 1.3 and major areas are listed below in Table 1.3.

Table 1.3: Sectors of MSMEs

Food Products	Chemical & Chemical Products
Basic Metal Industries	Metal Products
Miscellaneous Manufacturing Industries	Rubber & Plastic Products
Machinery & Parts Except Electrical goods	Hosiery & Garments - Wood Products
Non-metallic Mineral Products	Paper Products & Printing
Transport Equipment & Parts, Other Services & Products	Leather & Leather Products

Hence, in terms of total scale of operations any positive change like integrating innovation as part of their day to day strategy will impact the Indian economy in a positive direction. This thesis intends to contribute towards Innovation and Design becoming an integral part of the small and medium enterprises. Henceforth, the term small & medium enterprises or simply ‘small enterprises’ is used in this thesis in place of the abbreviation – MSME for ease of use and readability.

According to the MSME act 2006, small enterprises are categorized as ‘manufacturing’ and ‘service’ enterprises as shown in the Fig. 1.4. The manufacturing enterprises being the producers of goods - are valued in terms of plant and machinery. The Service Enterprises are engaged with rendering services such as administration, logistics, marketing, maintenance etc.

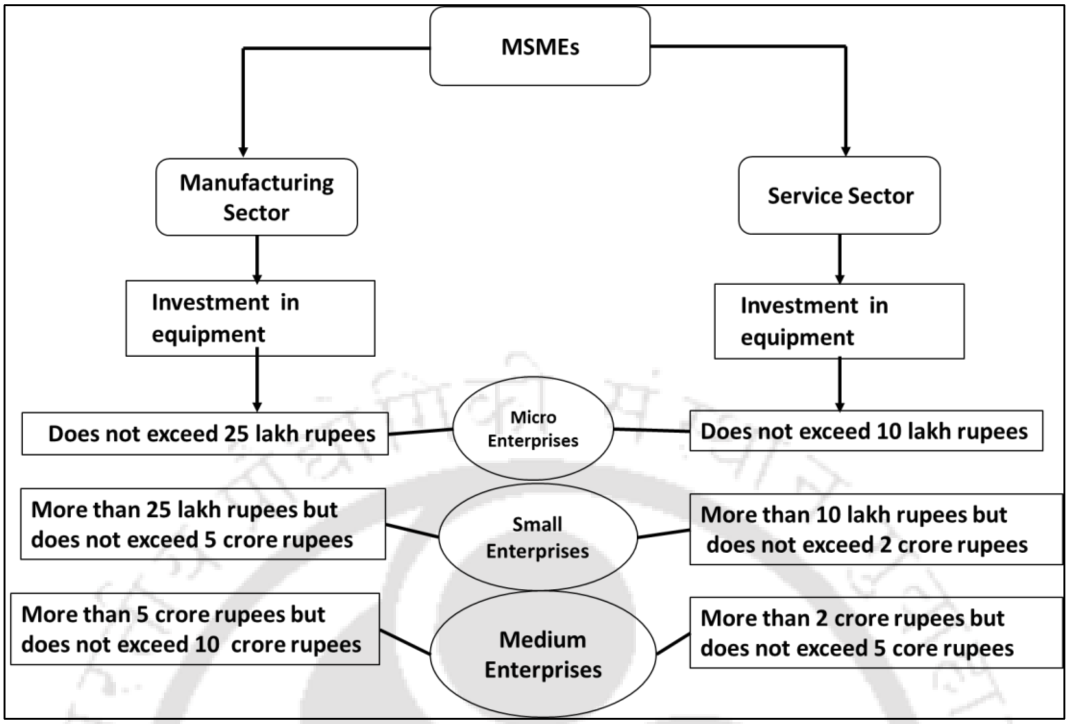


Figure 1.4: Structure of MSMES in Indian scenario

From the report cited earlier [Annual report MSME, 2017] which was released by Government of India, we can comprehend (Table 1.4) the number of micro, small and medium enterprises actively contributing to the economy of India. There is a steady increase in the total number of enterprises in one decade i.e. (1.72 lakhs in 2008 to 2.17 lakhs in 2016). The total volume of resources, jobs and range of products involved is enormous. Any improvement, however small will have a cascading positive effect across the spectrum. This thesis wishes to contribute to the process of innovation.

Table 1.4: Total number (in lakhs) of registered MSMEs in India

Year	Micro	Small	Medium	Total
2007-08	**1,53, 110**	**16,730**	**467**	**1,72,703**
2008-09	**1,70,262**	**18,792**	**702**	**1,93,026**
2009-10	**1,85,180**	**23,870**	**1,409**	**2,13,206**
2010-11	**2,05,112**	**29,125**	**1,263**	**2,38,429**
2011-12	**2,42,539**	**34,225**	**2,949**	**2,82,428**
2012-13	**2,75,867**	**41,502**	**5,449 3**	**22,818**
2013-14	**2,96,526**	**59,127**	**7,338**	**3,62,991**
2014-15	**3,46,206**	**70,933**	**8,219**	**4,25,358**
2015-16	**1,15,540**	**14,582**	**571**	**2,17,854****
****2015-16 information up to 30th September, 2015.**				

In this thesis the products coming under the manufacturing category are labeled as household white goods. These have been chosen as samples for analysis of innovative content. The word ‘Design’ used here indicates ‘User Centered Design’ and does not confine itself to ‘design of machine elements’ as solely practiced under engineering design.

In achieving innovation, the processes, design, performance and other factors will matter and the entire system complexity can be observed with their interlinking (Fig. 1.5). Capturing the links and unfolding them will lead to the path of innovation. As observed design has many creative tools and techniques that need to be implemented. There are many types of innovation rarely practiced in MSMEs. Currently, the use of advanced technologies and optimization techniques have made the process better. Collaboration with research institutes solves many problems related to materials and processes. The number schemes such as Make in India, Design clinics [Design Clinic Scheme, 2010], MSME clusters etc. initiated by Indian Government make MSMEs upgrade themselves. The Eco-system of the MSMEs which forms the context for this thesis is shown in the Fig. 1.5.

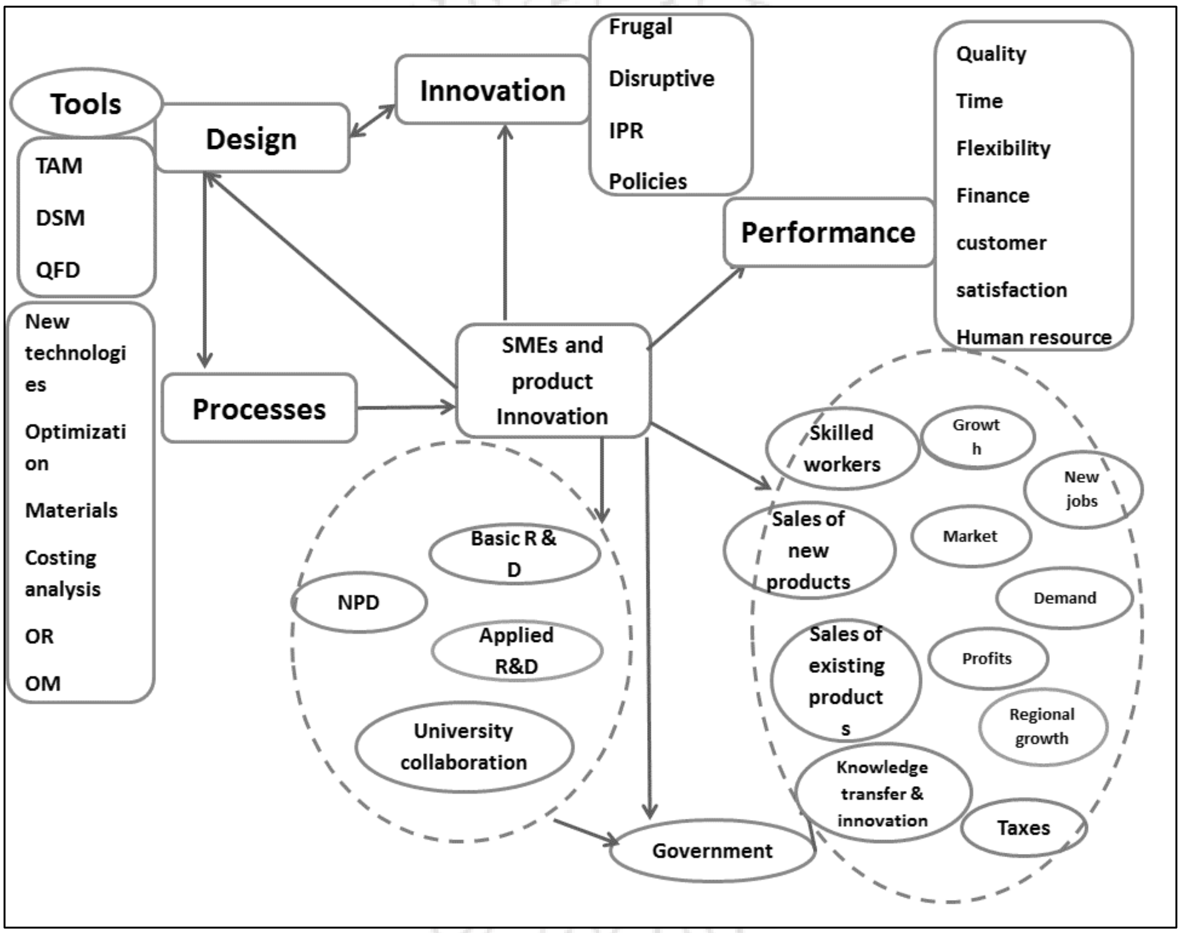


Figure 1.5: Eco-system of MSMEs

1.3 Innovation and its definition as used in this thesis

As stated earlier the term Innovation has many meanings as per the context and perception of people using it. It is used in a wide context to describe everything new or not seen before. It's frequency of use in popular media has already made it a buzz or fashionable trend term. Published literature reveals the word innovation in terms of types of innovation applications and it is represented in Fig. 1.6.

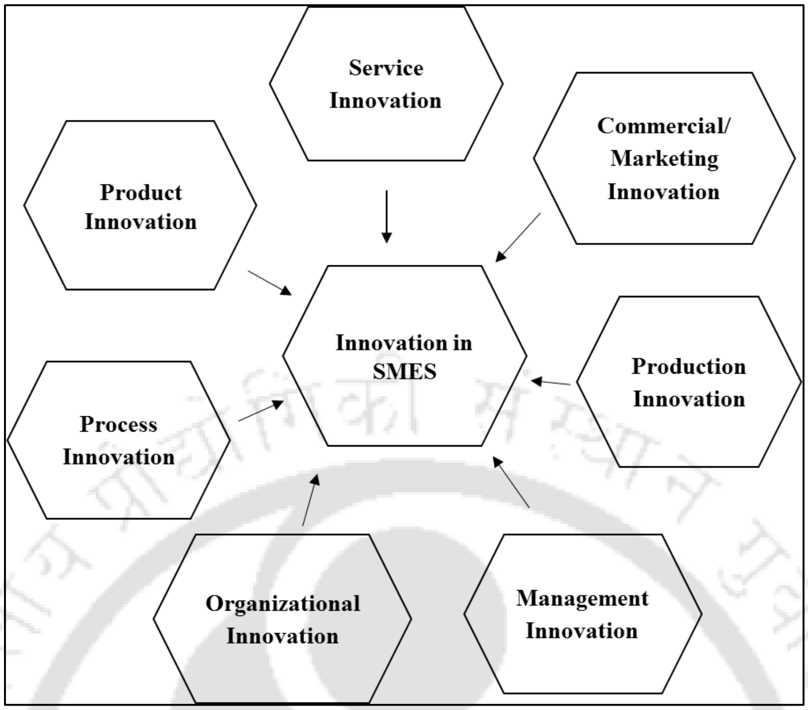


Figure 1.6: Areas of innovation application

Of the many definitions some of the ones figuring in publications are listed in Table 1.5.

Table 1.5: Different definitions of innovation by different researchers

Author	***Definition***
Drucker [2014]	Entrepreneur and entrepreneurship - the entrepreneur always searches for change, responds to it and exploits it as an opportunity.
Schumpeter [2017]	Introducing a new product or modifications brought to an existing product; A new process of innovation in an industry; The discovery of a new market; Developing new sources of supply with raw materials; Other changes in the organization.
Meads [2003]	A patentable solution (external verified uniqueness) with a differentiated business model that changes the basis of business for that specific industry sector.
Boer and During [2001]	Creating a new association (combination) product market-technology-organization.
Robert Bastarache [2010]	Value + Creativity + Execution = Innovation
Simmonds [1968]	Innovations are new ideas that consist of: new products and services, new use of existing products, new markets for existing products or new marketing methods.

In this thesis innovation means ‘adding value through design’ to an existing product or generating new product ideas by qualitative and quantitative analysis of the product’s components and features based on human centered need for fulfilling the criteria. Multi-disciplinary inputs from knowledge domains such as Usability Engineering encompassing Interaction design, Ergonomics and Aesthetics are relied upon, in addition to classical approaches in engineering. These are used as a means of finding specific areas/components/subassembly in a product's physical configuration to enable adding utility value through creative design thinking. Therefore, making the product becomes more usable and useful.

1.4 The Role of Design in product innovation

Growing interest in design and innovation has resulted in strategies like design driven innovation [Verganti 2008; Hobday et al., 2012; Noble, 2011] which creates new meaning to the users. In this thesis innovation is driven by design thinking as stated by Verganti [2008] and Hubdy et al., [2011] and contemporary design researchers such as Brown [2009] and Norman [2013]. Researchers in Usability and Interaction design [iitg.ernet.in] have been adopting the – 'innovate through design' paradigm for over a decade in India.

Practitioners and researchers in search of different approaches to innovation are increasingly adopting the design route as it has different creative approach in comparison to the fixed logic of engineering analysis aiming at one solution. Innovation necessitates multiple explorations and multiple solutions. Having multiple solutions becomes easy to solve any complex and wicked problems [Bruce and Besant 2002]. Design is not about only form, function and visual appearance, it has other attributes such as semantics which deals with meanings [Yammiyavar 2005; Verganti 2008]. The Design thinking involves creative problem solving in the User Centered Design (UCD) approach [Borja De Mozota 2009]. User Centered Creative Design approach goes beyond engineering optimized solutions thereby multiplying the chances of innovation. Therefore, becoming effective and successful in adding value. To add value, one needs to go beyond the optimization boundaries. Often it is observed that the words 'Design' and 'Innovation' are used interchangeably in design discussions and discourses. In this thesis Design is associated with thinking, visualizing and creative imagination. Whereas, Innovation as used in design is mostly associated with invention and incremental improvement in the physical features of a product, including its sub components and assembly.

The work reported in this thesis relies on Concepts and Knowledge (C-K theory) [Hatchuel and Weil 2003], which propagates conjunction to disjunction within existing knowledge base and creating something new out of it. This thesis adopts the knowledge management cycle - from 'conjunction to disjunction to conjunction'. Design led innovation is achieved through 'analysis – synthesis' approach and it can be applied to the product's design, to identify parts and pin point spots that can be innovated by value addition, driven by user needs and usability. As stated by [Polyani, 2009] a user's interaction with the product can be understood by the users 'implicit – explicit' knowledge. Accordingly, the interaction with the product forms the basis of developing a new framework for innovation specifically for MSMEs and products manufactured by them.

In this thesis a new framework is proposed which aids the small enterprises to innovate their products using creative design thinking principles and practices in usability engineering. The framework was developed based on methodology and philosophy of creative product design. [Cross, Nigel 1989]. It is therefore a Design led innovation framework/model.

Some definitions we come across and frequently quoted in research literature are Herbert Simon's [1969] "transformation of existing conditions into preferred ones". It is also stated in literature as ‘to devise courses of action aimed at changing existing situations into preferred ones’. Hesket [2005] defines design as “design is to design the design of a design” meaning a general concept, an activity a plan or intention a finished outcome, product. Design is used both as a noun and as a verb. In this thesis when design is used as a verb it is in the realm of methodology or morphology. When it is used as a noun it is meant as a descriptive outcome of the act of designing (v) - the object resulting from the act of designing.

The word ‘Design Thinking’ is the thought process behind an approach to innovation that takes as the starting point the deep understanding of the customer needs and employs an iterative prototype-and-test process to develop new solutions. The methods and approach applied in Design Thinking process are well suited for situations of uncertainty, where the desired outcomes or underlying market needs are unclear or unknown. The creative act of imagining, visualizing and iteration that happens in the mind of a designer while he/she is solving a design problem is ‘Design Thinking’. Since this process is invisible it (Design thinking) is often described in written terms of the stages of the process from spark of an idea to its development to its manifestation.
In this thesis Design has been taken as a cognitive thinking process of conceptualizing or solving problems using creative idea generation.

1.5 Objectives of the research study

The main aim of this research is to develop a relative innovation index for the products that are manufactured by Indian MSMEs and provide a framework for measuring innovation incorporated during product designing morphology. Following were the main objectives of the research:

Ob1: To develop innovation framework that can be adopted by Indian MSMEs.
“To identify research gaps through a literature review, and to propose a method that meets those research gaps”
For this, one must start with identifying all the variables that influence the innovation incorporation in a product during designing phase - specifically for MSME products.

Ob2: To propose a framework that can act as morphology for incorporating Innovation by MSMEs.

Ob3: To develop a measure or metric for innovation such that degree of innovation between two products can be compared relatively.

Ob4: Conduct an initial validation of the proposed framework.

1.6 Questions that motivated the Research

Having described and set the background in which this thesis is contextualized, we state the research questions that prompted us to take up this research.

RQ1. Can the MSMEs be provided with a methodology, using which they can add value to their products through design?

RQ2. What are the current levels of innovation practices in MSMEs, are they proficient and beneficial?

RQ3. How to select product concepts that have higher innovation content while they are generated during designing phase?

RQ4. Can we develop a framework for achieving, comparing and indexing innovation during a product's design phase that can be used by the MSMEs themselves without the need of outsourced expertise?

1.7 Chapter Summaries and Organization of the Thesis Report

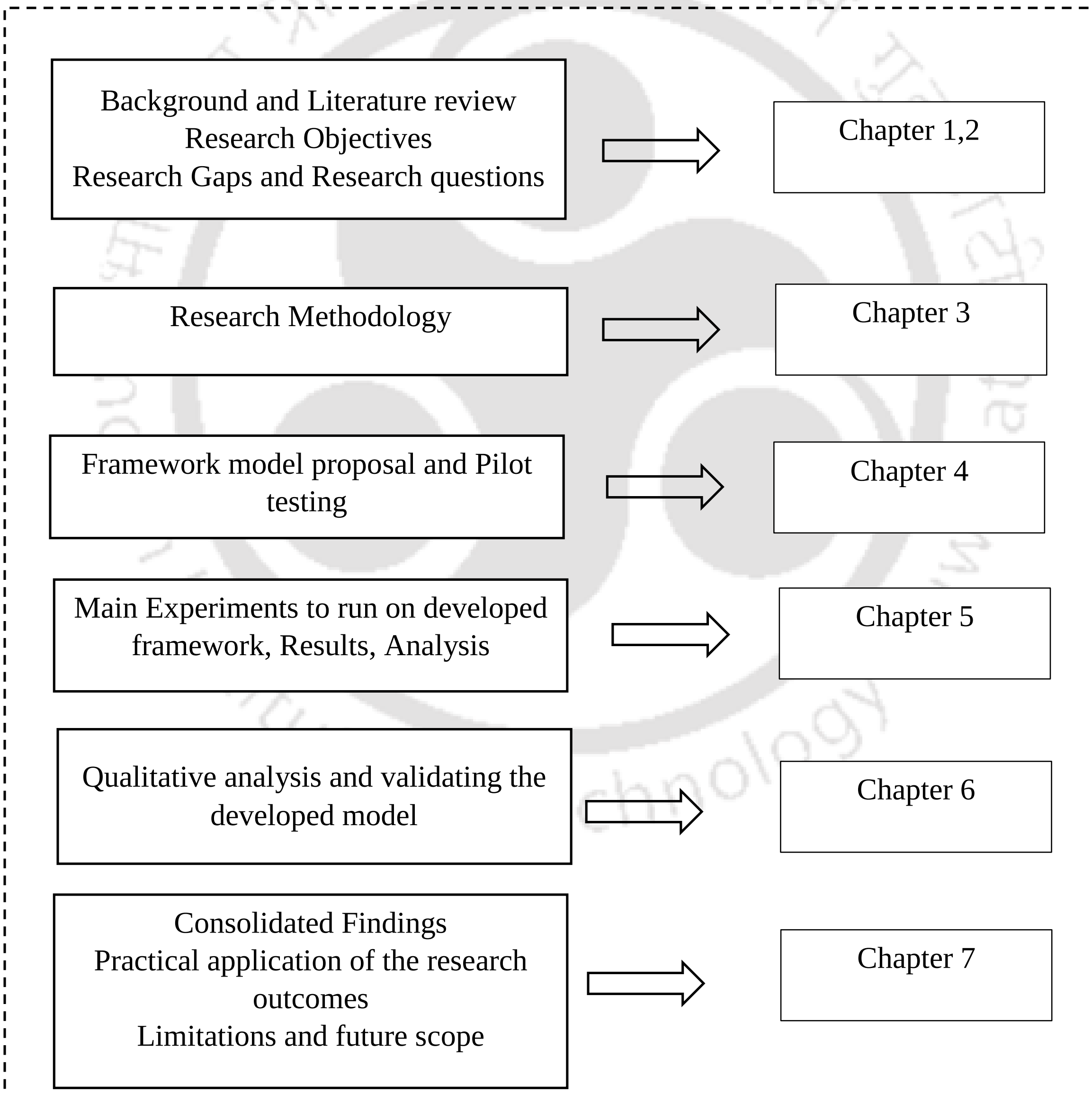


Figure 1.7: Chapter break up followed in the thesis

Chapter 2: The literature surveyed on MSMEs and innovation in product design has been presented. MSMEs' practices, problems in aiding innovation and need of innovation measurement in product design has been discussed. Previous product design, innovation models, theories, innovation measuring tools and techniques has been reported along with their suitability and drawbacks. Available tools and techniques in product design promoting innovation by other researchers has been outlined and important tools that can be utilized by the MSMEs have been evaluated heuristically. The survey features the results of the previous investigations and reports the gaps for the further exploration/research. Broad research questions based on the gaps in the areas of innovation, product design, have been raised. This leads us to the next chapter wherein detailed methodology and experimentation planning has been discussed.

Chapter 3: This chapter explains the methodology of the study performed for the current research. The initial studies, interviews and discussion are included. The design of experiments, participants and products chosen for the study along with surveys conducted for the research also are included.

Chapter 4: This chapter presents development of innovation framework and their basis, followed with experimental methodology as a pilot testing of two products. Identifying design elements, influencing innovation in product design for developing fractal triangle of innovation framework for concept selection matrix and prioritization of design elements has been discussed. Product analysis steps and design audit has been described along with the pilot study. Detailed Design Audit has been carried out on identified category of products in the next chapter as main experiments.

Chapter 5: In this chapter detailed product analysis has been covered through the various case studies. Method of conducting product analysis and basic idea of implementation of innovation incorporated in the products are reported. Each step has been interpolated onto the proposed framework for innovation. The overall Linkography results have been discussed with the innovation index, framework for innovation and validated using design cases. This chapter reports the measurement of relative innovation scale. It discusses the current results of the investigation by shedding light on the overall improvement of the products, and it also measures the relative innovation index.

Chapter 6: In this chapter detailed qualitative analysis results are furnished in order to validate the developed frame work. One case study has been reproduced and discussed. The developed frame work gives the innovation index between two similar products. Based on the 10 MSME visits a qualitative analysis results have been discussed.

Chapter 7: This chapter provides the summary of consolidated findings, tasks completed, summating up the research questions with their findings, important outcomes, recommendations, along with contribution of the thesis. Future scope and limitations of the current study have been presented.

Appendix: There are 4 Appendix included in this thesis. Appendix A, consists of questionnaire, for content analysis and other survey to find out the effectiveness of our method with MSMEs and survey photographs. Appendix B, includes templates developed for survey while prioritizing of design elements, Usability testing and product survey. Appendix C, mapping of ISO standards with identified design elements, followed by paper publication list in Appendix D.

Summary of chapter 1: In this chapter we presented our inspiration for exploring innovation in products specially for Indian MSMEs. Definitions and important terms utilized in this research were listed. The research questions and research objectives have been presented. The methodology used for research and research design and experimental design are explained briefly. Organization of each chapter of the thesis has been outlined and the next chapter presents literature study in detail.

Chapter 2

2. Literature review

Abstract: In this second chapter, findings of the literature survey have been analyzed and presented. Gaps and potential areas within new product development have been identified and presented in the form of research questions. Potential theories, morphologies, tools and techniques already in use in published works, that can be adopted in this research, have been identified and evaluated. The basic foundational frame of the research has been laid in terms of definitions and understanding of innovation relevant to the thesis.

2.1 Introduction - Literature survey plan

The research problem investigated in this thesis pertains to the topic of innovation. The aim is to improve the designs of products manufactured by MSMEs. As the research problem is multidisciplinary, the literature survey carried out covers a range of areas and topics as shown in Fig. 2.1. The Table 2.1 shows the number of publications reviewed as a part of the literature survey. To collect firsthand experience a field visit to a few selected MSMEs was undertaken, which has been collated and presented. The finding of the literature survey has been analyzed and presented under sub categories. Gaps and potential areas within the new product development have been identified. The basic foundational frame on which the remaining part of the research was done has been laid out at the end of this chapter. Starting with the term Innovation, the literature review of various areas is presented.

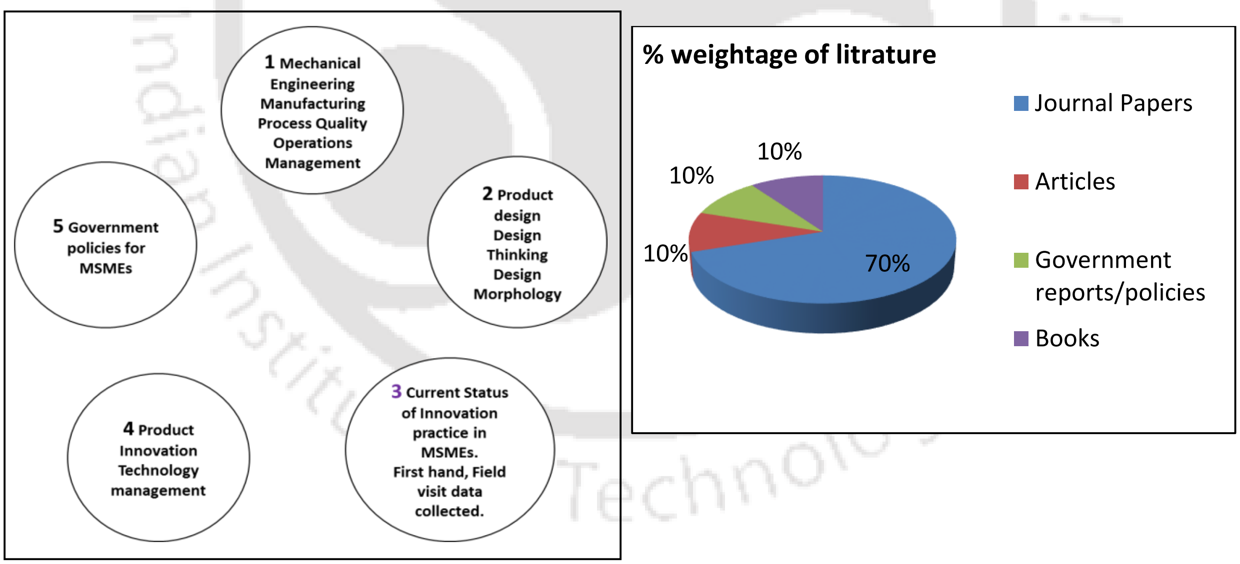


Figure 2.1: Literature study areas covered in this thesis.

Table 2.1: Shows the number of publications reviewed

Literature based on	Total numbers reviewed
MSMEs, management	140+
Innovation	
Product Innovation/Technology Management	
Manufacturing/Processes/Quality	
Design/Design innovation/Design thinking	
Books	25
Articles and Government reports	20

We followed a literature survey method, starting with area of interest, subject and then specific domain along with the keywords. The publication sources included were from Conference proceedings, Government documents, Journal Articles, Books, Newspapers etc. Search parameters were identified on key words based on the research topic. Standard journal publications are referred, articles published as grey literature, newspapers, Government reports etc. have also been reviewed. The conference papers, which gives the latest insights about the research area, inputs from SME associated people have also been referred.

2.2 Practices and Contributions of MSMEs in Indian context

Capability of MSMEs in contributing towards growth of economy is enormous as shown by the market share and sectors in Fig. 1.3 and Table 1.3 in chapter 1. However, MSMEs are far too slow in adopting innovation practices compared to their counterparts in other countries. An informal analysis carried out after initially visiting a few MSMEs it became evident that the methods, practices and tools being used by MSMEs are indeed outdated. The study reveals that MSMEs in India are rather slow in adopting innovation practices resulting in new products (More details are discussed in chapter 3). They have an enormous potential and capability to enhance the quality of products in terms of cost, material, ergonomics, aesthetics, functionality etc. MSMEs are not focusing on the need for innovation in line with the India's strategy for 'Make in India' thrust.

In this study it is posited that if MSMEs are provided with design and innovation tools specifically tailor suited to them, they are likely to be adopted and absorbed. This research attempts to answer the question - if one were to provide simpler product designing tools that have 'innovation' strategy built within them, what could they be, given the limited resources that MSME's have? MSMEs in India are more driven by 'market - quick return' policy rather than invest in innovation. However, the statistics of their contribution in terms of the employment percentage of industrial workers as well as the turnover indicate that even if an incremental degree of innovation is practiced its benefits to the MSME sector will be multifold.

The Indian economy will grow by over 8% annum until 2020 and will be topping the list by 2050 [Growth drivers for tomorrow, 2015]**.** However industrial experts believe that this target would be difficult to achieve without active participation of MSMEs and GDP reaches to 22% in next 3 years. Nearly 60% MSMEs fall under unorganized sector. Though India is firmly on the trajectory growth yet there are issues hindering growth of MSMEs [Sethi, 2014] and the same has been reported by many earlier cited authors and reports.

Based on the readings of reports and industry trade journals we can infer that

- Product innovation could be the key factor for the growth of MSMEs in terms of profits, competitiveness economically as well as technologically.
- To achieve product/technology innovation it requires product planning and design capability, service capability and knowledge assets.
- There is a need for study to understand and bring product innovation/technology innovation in Indian MSMEs by evolving guidelines for the practice of innovation across the organization.

2.3 Innovation and Indian practices

In recent years, large scale industries have undergone many changes in their production environment by implementing various manufacturing techniques such as Just in Time, Total Quality Methods, Six Sigma, Value methods and Lean manufacturing. Odedairo & Bell [2010] developed a toolkit such as Return on Investment, Cost modeling, Pareto analysis, Value stream mapping, Quality Function Deployment and target costing as represented in Fig. 2.2.

Large scale industries have adopted WCM such as JIT (Just in Time), TQM (Total Quality Management), BPR (Business Process Reengineering), FMS (Flexible Manufacturing System), CIM (Computer Integrated Manufacturing) and lean and agile manufacturing and many other techniques. Also, some QI (Quality Index) tools, Statistical Process Control (SPC) techniques, are discussed by Mathur, A. et al., [2012]. Bewoor & Pawar [2010] discussed about Design of Experiments (DOE approach), Taguchi and Shainin methodology and Shainin methodology found to be useful, which was confirmed by an Indian SME ISO/QMS certification.

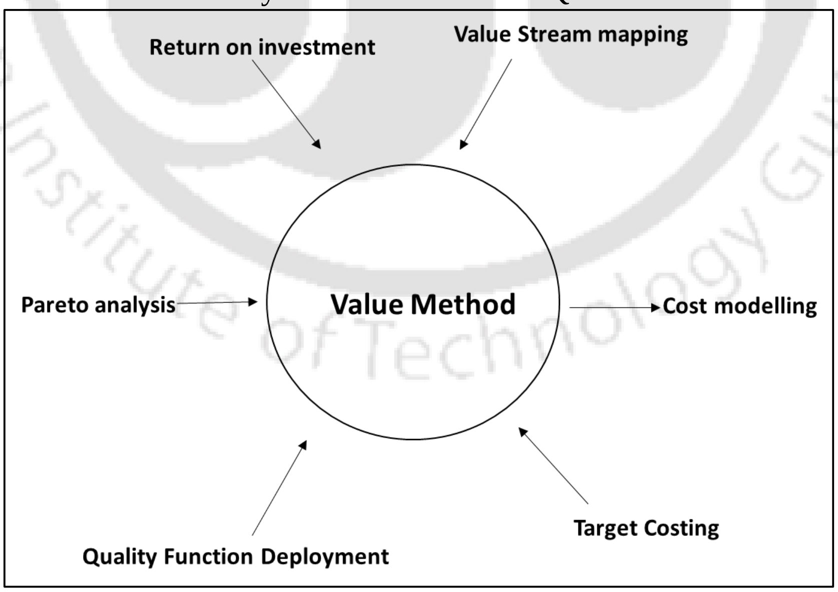


Figure 2.2: Practices of tools aiding innovation adopted from Odedairo & Bell [2010]

Brem & Voigt, [2009] Fig. 2.5, discusses on the commonly used terms such as jugaad, frugal innovation, frugal engineering, constraint-based innovation, Gandhian innovation, catalytic innovation, grassroots innovation, indigenous innovation and reverse innovation. These innovation types are developed based on the local need and practices, and they have not followed any methodology or theories. Such innovations are not commercialized to the level of competition and marketing to fetch profits. They do fulfill a social and community need however inefficient they may be. Lee, S. et al., [2010] proposed an open innovation model shown in Fig. 2.3. Rao [2013] proposed a frugal innovation model as represented by Fig. 2.4, but such practices are missing in the day to day workings of Indian MSMEs. The model is based on collaboration between MSMEs which increases the overall innovation levels.

Tata Nano that resulted from a collective vendor cum designer team collaborative work within MSMEs is the best example of innovative product discussed in Indian management journals. Innovation happened, cost was drastically reduced and the whole world was stunned by seeing the result. Hence there is a case for collaborative innovation amongst MSMEs. This requires a collaborating task force on the top. However, most MSMEs in India are small enterprises and work independently and have no concept of exchange of knowledge between collaborating industries. Even in the case of Tata Nano car, while everyone agreed it was innovation at its best, there were very few discussions or publications on the innovation embedded inside the product. And it was not possible to use an innovation index to compare it with any other car purely in terms of innovation inputs. Hence, there is need for a metric of innovation.

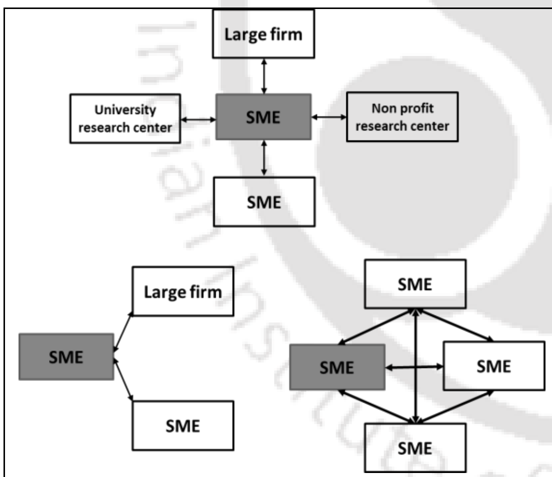


Figure 2.3: Open innovation model by Lee, et. al., [2010] adopted and redrawn

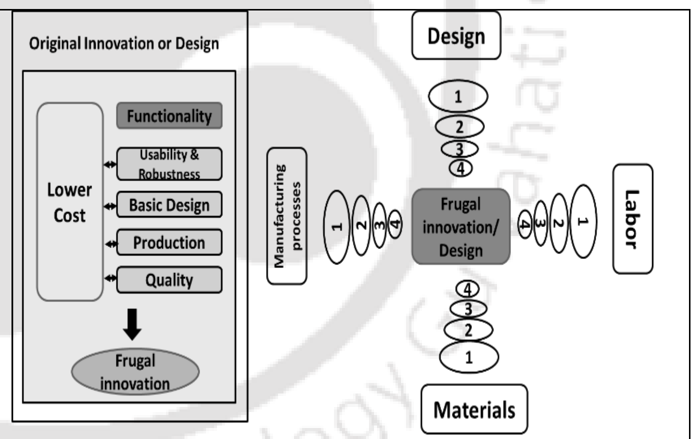


Figure 2.4: Frugal innovation by Rao, [2013] adopted and redrawn

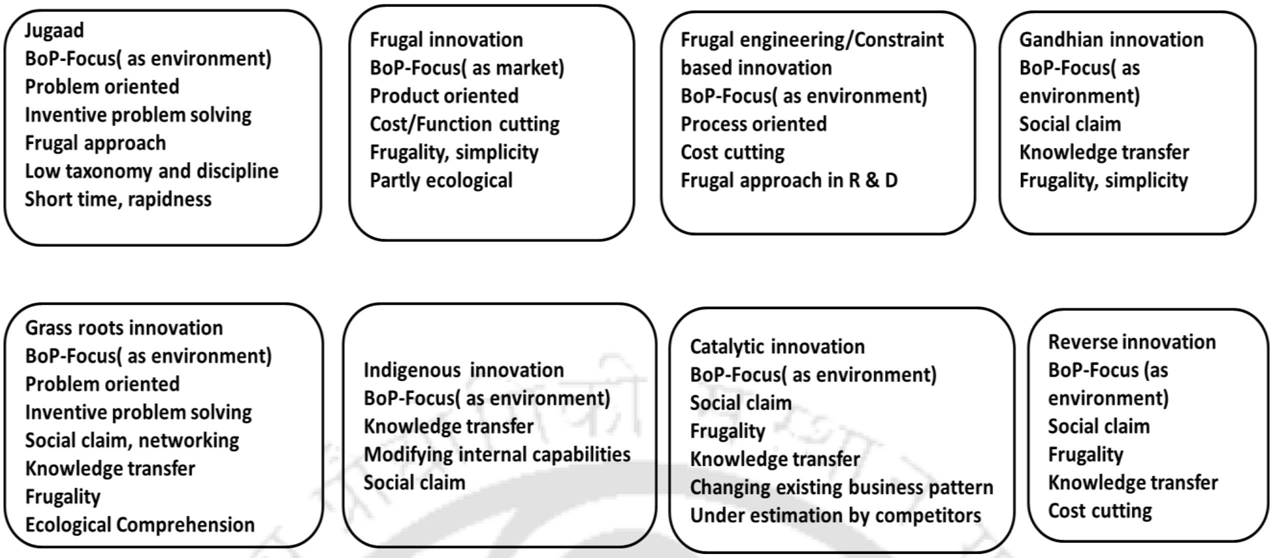


Figure 2.5: Different types of innovation as discussed by Brem and Voigt, [2009]

MSMEs practices and performance have an impact on innovation, individual interest and perception, which is discussed below.

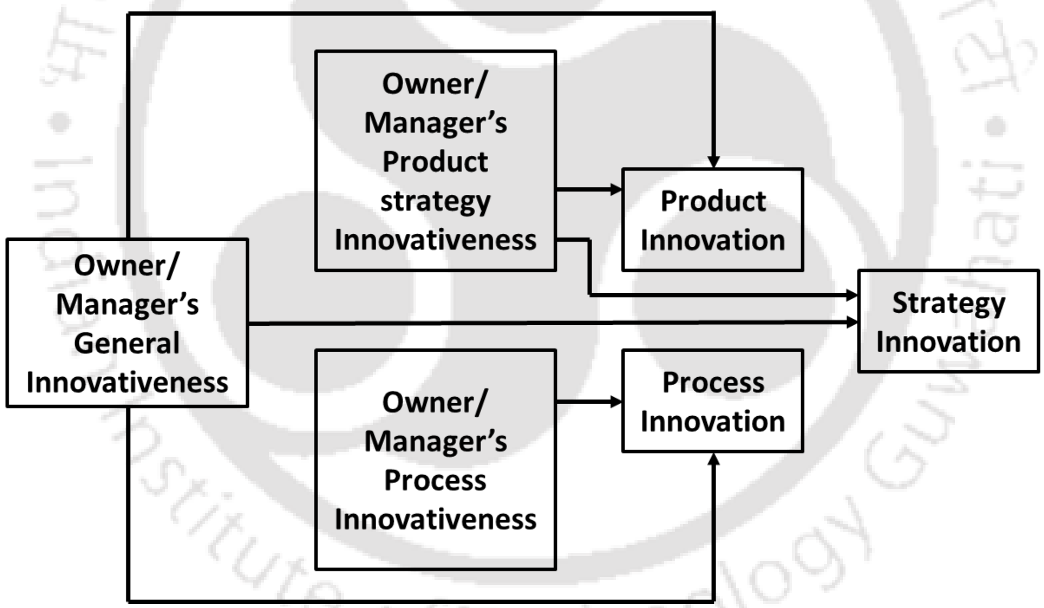


Figure 2.6: Model by Alam and Dubey, [2014] on the innovativeness and its relations to the innovation in MSMEs adopted and redrawn

Innovation related literature describes that innovation and performance is related more or less only to big firms (MNCs) not in MSMEs. Innovation in any firm is closely correlated with the consumer/user. One of the studies showed [Audretsch, 2001; Tether, 1998; Eden, et. al., 1997] showed that the innovation and performance of large firms is very much different from the MSMEs. The same empirical relationships, models and methods cannot be used directly in MSMEs. Jimenez-Jimenez and Sanz-Valle, 2011; Bell, 2005; Cho & Pucik, 2005 claimed in their study of introduction to innovation that for the success and sustainability of a firm, innovation plays a key factor to be competitive in the market [Bartel & Garud, 2009; Johannessen, 2008; Mumford & Licuanan, 2004].

Many investigations reported the relationship between capturing the market and firm's performance. Narver, et. al., [1998], showed a positive relationship between market orientation and firms profitability in case of larger firms. Jaworski & Kohli, [1993], showed the empirical evidence of strong positive relationship between market potential and performance of big firms. These studies on innovation performance of firms was largely confined to big firms and not to the MSMEs. It is hard to find any empirical evidence on the relationships, factors, methodology for achieving innovation in MSMEs, in published literature.

Alam & Dubey [2014], have worked on the innovativeness and its relations to the innovation in MSMEs. Their study evidence/claims that owner/manager's innovativeness largely decides to initiate innovation activity of the firm [Verhees & Meulenberg, 2004]. Many researchers have argued that the personal innovativeness of an individual plays a vital role [Goldsmith, 1990; Alam & Dubey, 2014], study shows evidence of the level of owner's/managers innovativeness in product, process and strategy relationships as shown in Fig. 2.6.

To be relevant in competition there should be continuous innovation in the firm. The current trends of the products are changing according to the customer/user needs and tastes, latest technologies, new materials, reduced product life cycles and increased competition. Hence, it is expected that all firms should innovate regardless of size and sector to survive in the market. Therefore, there is a need for the method/tool in achieving innovation in products especially in terms of user centered design. Our current research focusses on these issues and to develop a scale for measuring innovation. Also, the study will emphasize on the areas of improvement in the given set of/family of products.

Some more research articles are summarized in the form of Table 2.2 along with gaps in MSMEs and innovation with subjective description.

Table 2.2: Summarized description of the literature review on innovation and MSMEs

Author	**Subjective description**	**Missing links/Remarks**
Gupta, [2009]	Stimulating demand, Technology upgradation and skills, NPD services, R&D, Grass root innovation.	How to achieve innovation or methods/techniques were not discussed.
Scozzi, et.al., [2005]	Business Modelling Techniques, Process innovation emphasized, Areas identified for improvement along with methods decision making, learning support, work flow and role active diagrams and tools for performance measure.	Focused on (BMTs) process innovation models and does not assure the success in process innovation.
Hu, [2014]	Business model and technological innovation, Insights on efficiency centered business model, design, novelty centered, organizational learning, technology and innovation in Chinese firms is focused.	Focused on BMTs, Management and managers to bring technological innovation.

Subrahmanya, [2005]	Comparative study on India and UK MSMEs, compared policy differences of both for innovation, Problems in Indian MSMEs is focused, like less invention and innovation and low R&D etc.	Study on Indian and UK MSMEs, Problems highlighted in case of India, Lower design thinking making lower capability of innovation.
Hogan & Coote, [2014]	Study of process support innovation, Scheins multi layered model of organization cultural process that support organizational innovation tested in service firms.	Discusses about the cultural process and organization innovation on the basis of Scheins model.
Laforet, [2008]	It shows the relation between size, strategic and market orientation along with innovation.	Does not suggest any model or method to aid innovation
Balasubramanya, [2005]	Poses questions on how to promote innovation? Quality of innovation, patenting culture in Indian MSMEs	Much focus is upon policy recommendations.
Lee, et.al., [2010]	Types of innovation, various models studied in Korean MSMEs, Proposed an open innovation model.	Collaborations with in MSMEs and large firms to achieve innovation was suggested
Krishnaswamy, et. al., [2014]	Case study of Auto component manufacturer in India, Entrepreneurs encash the opportunities, in house technological capability, External assistance to achieve innovation. Incremental innovation and constant customer feedback systems lead to the innovation.	Study was carried on 3 auto components, not developed any system or entirely new product, methods or tools for aiding innovation. Market opportunities converted to usable components terming it as innovation.
De Saa-Perez, et. al., [2012]	Role of training to innovate in MSMEs, it integrated theoretical approaches of HRM, KM (Knowledge Management) on training can lead to innovation. Innovation as dependent variable, training and KM are explanatory variables. Descriptive study was carried.	Training increases the level of innovation and growth of firm. For Indian MSMEs it is difficult to arrange training.
Antonioli & Della, [2015]	Adoptions of organizations and technological innovation with investment in training activities. Internal and external training and investment effects on MSMEs.	Study reveals that no significant relation with training and technological innovation.
Van de Vrande, et.al., [2009]	Open innovation practices in MSME, motives and perceived challenges when MSMEs adopt open innovation, highlights on perceived trends, managerial skills and motivation.	Implications and types of open innovation are discussed.

Hungund, [2014]	Conceptual framework on open innovation practices, MSME characteristics, business eco system and sustainable growth.	Guiding tool for Government policies for innovation.
Rao, [2013]	Features of frugal innovation, feasibility and optimization of basic design.	Design methodology and frugal innovation.
Brem & Wolfram, [2014]	Jugaad, Frugal, Gandhian and other types of innovations have been discussed.	Classes of innovation were discussed.
Bala Subrahmanya, [2013]	Internal factors in MSMEs to obtain external support from Government, MNCs, universities, R&D institutes to cater innovation. Competency level of entrepreneur and man power, an exclusive design center leads to product and process innovation.	Study was carried only for 3 contexts. It yields the firm level factors, external support and innovation performance - analytical frame work.

2.4 Literature on the phenomena of Innovation and Creativity

Innovation has many definitions and it is used in many contexts with different shades of intended meanings. Management expert, Drucker [2014] defines innovation as responding to need for change as seen in the quote "entrepreneur and entrepreneurship - the entrepreneur always searches for change, responds to it and exploits it as an opportunity".

The entire activity of an entrepreneur, according to Drucker [2014], can be described as the act of innovation. Drucker's views are more from marketing point of view wherein the need to occupy and dominate marketing space calls for continuous innovative decision making. In this thesis innovation is used partly with the Drucker's point of view as well as from the designer's point of view of problem solving using creativity. Innovation as defined by Robert Bastarache [2010] connects the 'process' to the 'end' result. Bastarache defined innovation as the summation of value, creativity and execution. Innovation is the blend of desirability, feasibility and viability. The desirability is the likes of a user, feasibility is what can be achieved with the technology and viability is the ability of the design to be realizable. Innovation therefore is not confined to 'feasibility' (related to technology) but could also be done in the area of 'desirability' (related to user).

Other definitions of innovation in literature are based on description of types of innovation. Innovation can be of various types [Trott, 2008] like product innovation, process innovation, organizational innovation, management innovation, production innovation, commercial/marketing innovation, service innovation etc. as shown in Fig. 1.6. discussed in previous chapter. Innovation has many other definitions/descriptions some of which are listed in the Table 1.5 in chapter 1.

Innovation has also been often defined through a 'model', Cropley et. al., [2011]; Oman, et. al., [2013] provide a useful definition for creativity and innovation of engineering products in which creativity is a four-dimensional, hierarchical model that must exhibit relevance, effectiveness, novelty, elegance and 'generalizability' as shown in Table 2.3 below.

Table 2.3: Levels of creativity in products adopted and redrawn from Corpley et. al., [2011]

Criterion	Kind of Product				
	Routine	Original	Elegant	Innovative	Aesthetic
Effectiveness	+	+	+	+	-
Novelty	-	+	+	+	+
Elegance	-	-	+	+	?
Generalizability	-	-	-	+	?

Innovation has also been described as a path. The Fig. 2.7 shows the path according to Naiman [2013], in which the innovation is obtained if design thinking is implemented.

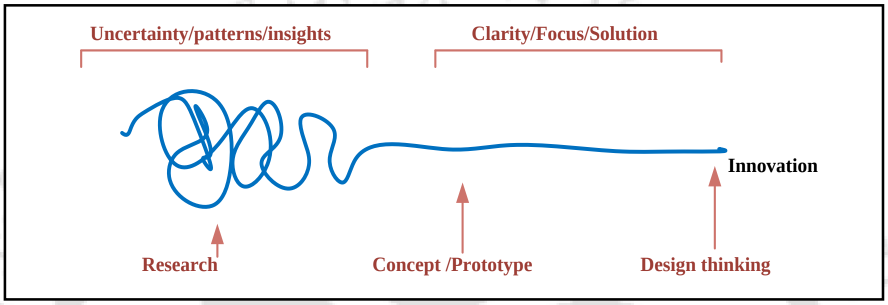


Figure 2.7: Path to innovation adopted and redrawn Naiman, 2013.

The word 'Innovation' is widely used in public advertisements and popular newspaper articles so much so that it has become a hype or jargon in management and business. However, its essence is felt only while practicing it and its difficulty is understood when one wants to measure the level of innovation that has taken place. Learning and teaching innovation is increasingly confined to knowing about it rather than knowing how to practice it. The word 'innovation' is often linked to the word 'design' as found in literature. Naiman, [2013] has mentioned in her frame work for creativity and innovation (Fig. 2.8), about the iterative tasks in product design indicating the underlying complex processes. The framework gives different steps which a designer need to think through to finalize an idea or concept. Designers often use the word 'think' to characterize the abstract process of creative visualization.

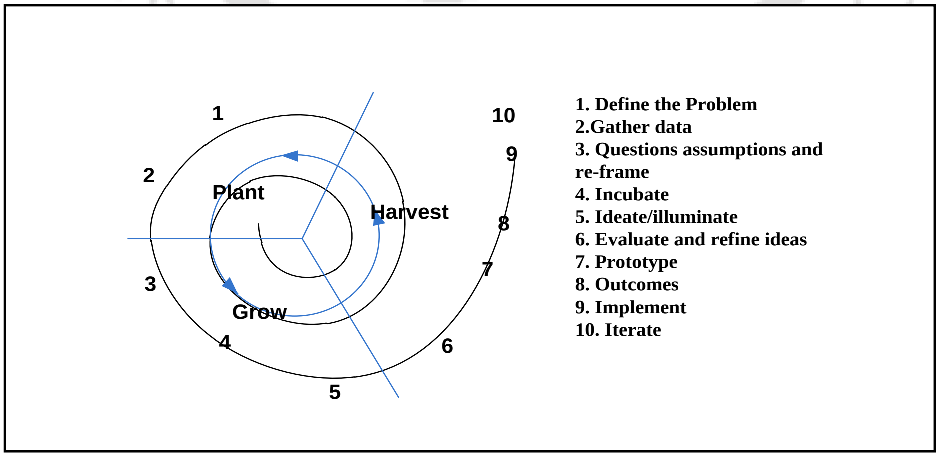


Figure 2.8: Framework for Creativity and innovation adopted and redrawn from Naiman, [2013]

The word 'Design Thinking' is the thought process behind an approach to innovation that takes as the starting point a deep understanding of the customer needs and employs an iterative prototype-and-test process to develop new solutions. The methods and approach applied in Design Thinking process are well suited for situations of uncertainty, where the desired outcome or underlying market needs are unclear or unknown. The creative act of imagining, visualizing and iterating that happens in the mind of a designer while he/she is solving a design problem is 'Design Thinking'. Since this process is invisible it (Design thinking) [creativityatwork.com, 2016] is often described in written terms as the stages of the process from spark of an idea to its development and its manifestation.

There are several methods mentioned in literature to assess innovation and creativity in the designing processes. Muller & Thoring, [2012] compared two different design innovation models, process model for design thinking and lean startup. The major difference is process models work in a linear way and lean process in a circular way, both processes have 6 steps. Design thinking process model is User Centered and lean startup is customer oriented. Both have similar end goal yet there is no sharing of knowledge. If both strategies are known and combined it results in more innovation in projects of small enterprises.

Two broad factors have been identified that could assist in the measurement of innovation. They are (i) Novelty (ii) User Centered specifications, that have become a criterion for design evaluation. A novelty in a product is an indicator of embedded innovation. This is known to the designer but not necessarily to the MSMEs. As reported by Justel et. al., 2007, the novelty of an idea can be evaluated by taking a degree of novelty as level of curiosity and its patentability. The degree of newness and a measure of innovation has many dimensions. Any product having more number of dimensions leads to high score and high degree of newness, leading to a higher degree of innovation prospect. A work carried out by Garcia and Calantone, 2002 is referred in constructing Table 2.4 to obtain the degree of newness. Apart from this, designers can contribute in assigning the degree of newness, based on their experience and knowledge of product.

Table 2.4: Dimensions of Newness in Products (Discontinuities, Garcia and Calantone, 2002)

Relationship of the product	Dimensions of newness
New to-	World, Industry, Science and technology community Market, Firm, Customer.
New in what? –	Technology, Process, Product features, product design, Product line/assembly line, Service, Competition, customers need, Usage pattern, development skills, marketing/sales/distribution skills, Knowledge base, Quality etc.

User Centered Design criteria resulting from user centered needs are central in the Kano model. These factors are measurable and hence are being opted in this study as a possible metrics for innovation.

The design criteria are recognized and fixed in view of the customer's needs, feedback as carried in Kano's survey [Kano et. al., 1996]. It is observed that in general for any product to be successful, customer need has to be considered in designing phase rather than as an afterthought. If the customer feels his requirements are fulfilled, then automatically he is satisfied, which will lead to the success of the product.

Some of the commonly used evaluation processes include the Weighted Objectives Method [Pahl & Beitz, 1988; VanGundy, 1988; Box & Stephen,1992; Fogler et. al., 1995; Roozenburg & Eekels, 1995; Cross, 2008], Pugh's Method or the Datum Method [Pugh,1996], [Ulrich, 2000; Ullman, 2010]. There are many other methods reported in literature which help designers. Methods such as Robust Decision Making provide designers with a detailed account of what decision making entails? how to make robust decisions within team settings? and how best to evaluate alternatives? Many engineering design textbooks, such as Otto and Wood's Product Design [1998], Ullman's The Mechanical Design Process [2002], Pahl and Beitz's Engineering Design [1984], and Ulrich and Eppinger's Product Design and Development [2000], provide an overview of how to make design decisions when faced with numerous alternatives? They are very effective, but do not necessarily focus on creativity and innovation as integral design part of requirements. They approach innovation as a step by step process and not a specification or requirement. Therefore, the concept of innovation remains predominantly subjective. No measure or metrics is mentioned along with the subjective discussion in research literature which is a gap in knowledge. Comparison of two innovative objects cannot be done except for subjective expression of opinion. This thesis addresses this knowledge gap of not being able to quantify innovation even as an index if not in absolute dimensions.

Innovation has also been described in published literature as multidimensional in nature [Hauschildt and Salomo, 2011]. There is the Content Dimension and the Process dimension approach to understand innovation. This is because the word innovation is often used to depict a process or a result of a process. Degrees of innovation or an index of innovation for comparison is not available. Therefore, this thesis aims to fill this gap by attempting to come up with a frame work for an innovation index given two or more products that are functionally same.

To survive in the market, the organizations must commit towards innovation. Any organization working today must be exceptionally contending and challenging. There is a need to quickly adopt to the complex conditions, technology adoptions and changing economic situations. In accordance it is necessary to elevate the innovation competency, user needs, usability, development of new products, new and niche markets, competitions and profits.

Many MSMEs presume that they cannot use their full innovation capabilities. The reason being lack of expertise in an idea generation, implementation, skill development and investment to mention few [Brem & Voigt, 2009; Caloghirou et. al., 2004]. These MSMEs are aware that if they do not innovate they will fail in the long term. They fail to understand that innovation can happen at many levels such as organizational level, firms level, system level, product level etc., these must be captured and utilized for incremental innovation. For organizational and system level there are some models/methods available to describe and quantify innovation. However, these are measures of 'success' of an organization and they do not help in measuring innovation. As argued earlier there is no measurement method for indexing innovation in similar type of products or for comparison of competitor's products. From Fig. 2.9 the difficulty in measuring innovation in products of the same family is observed.

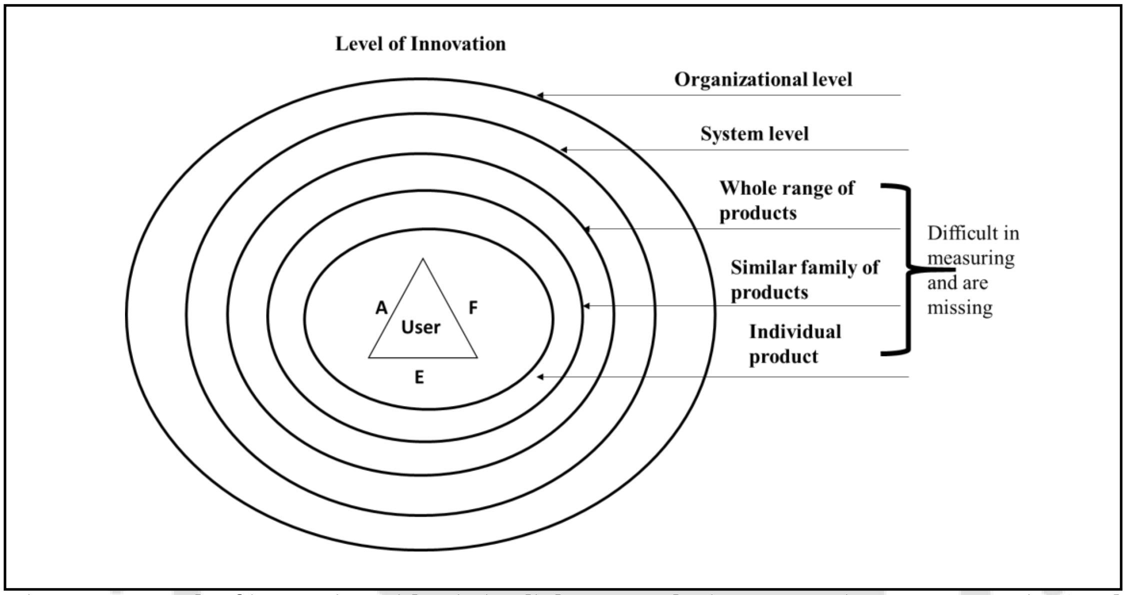


Figure 2.9: Levels of innovation with missing links, A-Aesthetics, F-Function, E-Ergonomics (Author generated)

In comparison to Indian MSMEs the European Commission sees innovation as the core of entrepreneurial initiative: "Almost any company owes its foundation, at least in relation to its competitors on the market, to an innovation. Market needs, better quality products, predicting the new product, cost reduction, organizing in better and effective, efficient way also termed as innovation" [European Commission, 1995].

Innovations are the global motor for economic growth and represent the key factor for competitiveness [Vives, 2008]. In 1934 this major work was published in the United States as "The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle", where Vives [2008] writes about the realization of new combinations by "the doing of new things or the doing of things that are already done, in a new way" [Schumpeter, 1982].

E.M. Rogers states that "Innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption" [Rogers, 2003]. This definition from Rogers entails that an innovation is more than a perception or meaning [Riedl et. al., 2009]. An idea initiates the innovation in product [Bullinger, 2008]. Market pull and technology push are the two major contributors for innovation [Brem & Vogit, 2009]. Innovation is an exceptionally complicated term and to understand the dimensions, Hauschildt and Salomo [2011] it has been characterized using four dimensions of innovation as depicted in Fig. 2.10.

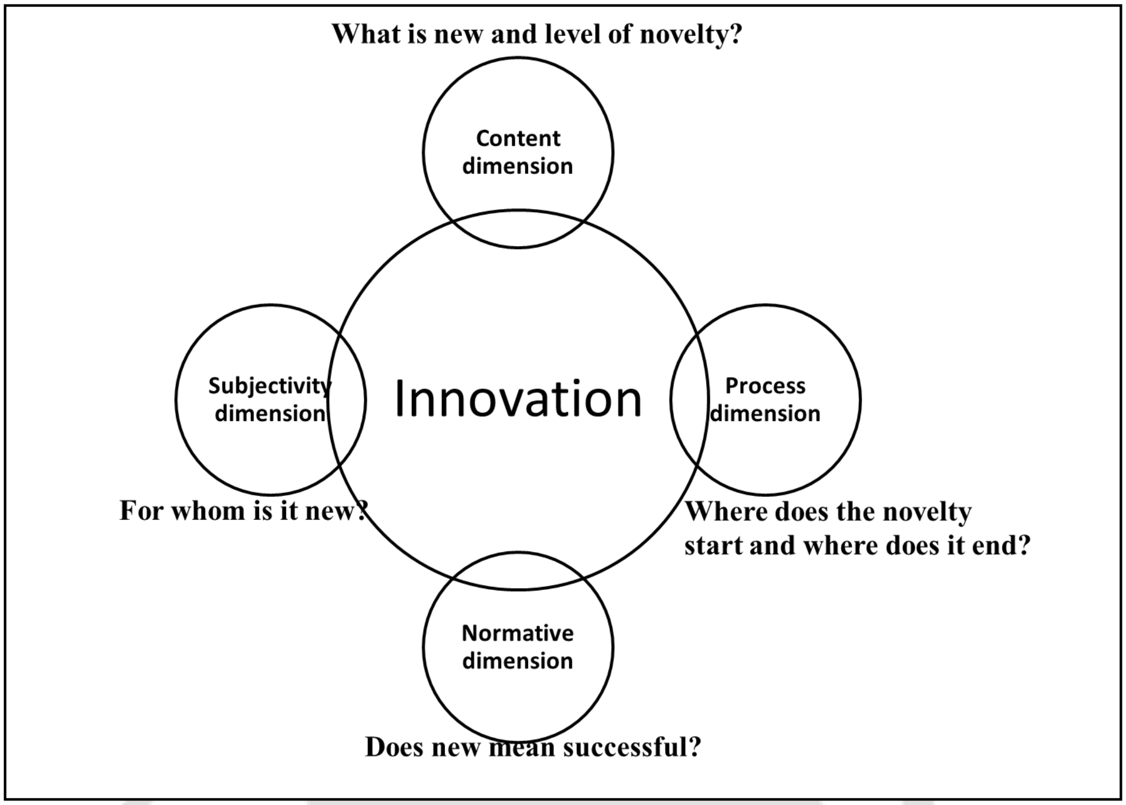


Figure 2.10: Innovation and its dimensions adopted and modified from Hauschildt and Salomo, [2011]

The Content Dimension addresses the following question: What is new and level of novelty? To be new and novel any activity depends upon the product and process already listed in the types of innovation in chapter 1. Another aspect is the degree of novelty [Justel et. al., 2007] and [Garcia, 2002] sheer innovation potential can be calculated with the help of developed framework described in chapter 3. Chandy & Tellis, 1998 gives the typology of innovation as incremental, technology breakthrough, market breakthrough and radical innovation which does not happen regularly. Here innovation does not mean only new or novel, it is also adding value to the existing product.

The subjectivity dimension asks the question - For whom is it new? It is very important to raise question for whom it is new or degree of novelty? It can be market perspective or entrepreneur perspective. This subjectivity dimension does not consider the users prospective, which is an important factor in innovation. The user has a vital role in judging and making any product successful.

The process dimension answers the question -Where does the novelty start and where does it end? which is a difficult question. On same lines, where does the innovation begin or end? In process dimension, the product development follows a process cycle. These are sequentially connected activities leading to innovation and it is a continuous iterative process.

There are many studies on the stages of product development such as Roozenburg and Eekels's model [1995], Analysis---Concept---Materialization; Pahl and Beitz [1988], Clarification of task--Conceptual design--Embodiment design--Detail design; Cooper model [1994,2011], Scoping--Build business case--Development--Testing and validation--Launch; Thom's innovation process model (Idea generation--idea acceptance--idea realization). Another recent framework reported is Innovation value chain (Idea Generation--Conversion--Diffusion) by Hansen & Birkinshaw, [2007]. In this process dimension, it is difficult to pin point the states/spots of innovation by any of these models. Therefore, the major area of focus in this thesis is to find out the innovativeness of the product.

Based on inference of the literature surveyed so far in understanding the term 'Innovation' - it is seen that the term innovation has many meanings as per the context and perception of people. It is used in a wide context to describe anything new. Its frequency of use in popular media makes it a buzz word or fashionable jargon. For engineers, micro, small and medium enterprises, innovating or creating new products through design is not a priority as they have limited access to resources for R&D. In design, the term innovation is an integral outcome of creative design thinking and problem solving. It concerns the product as well as the designer who conceives the product intended to solve a real-world problem. This is the working definition of innovation process adopted in this thesis.

It is argued in this thesis that the literature stated above is more of gross designing methods rather than innovation indexing and measuring tools. There seems to be a dearth of tools that measure degrees of innovation. The recognition of innovation, stage at which it happens and value addition are difficult to isolate based on whatever is known about innovation as applied to product designs.

One possible approach could be to perform a task analysis as the product's designing process unfolds. When tasks are broken down, each one can be mapped to incremental addition of value. It is expected that such values summation could be a metric for innovation. To focus on the integral design matrix, we need to choose the elements of design matrix. The next section briefly describes the elements used in the design matrix, which are ultimately used to measure the innovation potential. This in turn will help us to compare the designs which can range from simple to complex products.

Often the term 'creativity' is used in place of or in association with innovation. However, both are different as evident in their fundamental definitions. While there are not many publications on measurement or metrics of innovation, there are several cited research works on measuring creativity on a scale such as CPSS, CAT, SPAF, Moss metrics etc. [Oman et. al., 2013; Besemer, 1998; Amabile, 1982; Sarkar & Chakrabarti, 2008]. There are some models like Kano, Design structure matrix, QFD etc. that guide us to understand and quantify need, problem complexity, satisfaction and solution for the customers. In addition, metrics like ROI (Return on Investment of a novel idea) will give the profits on the investment which can become an indirect value measure for innovation. ROI is the measure of innovation by many MNCs as well as MSMEs in India and other countries. However, there are no direct metrics or measures of innovation mentioned in literature that are independent of process and dependent on the reason for object's existence. A metrics model if made available could be a boon to industry with limited resources such as small-scale industry or artisan enterprise in India. ROI gives the innovation competency of the firm but not the not the product. However, the basis of such metrics for innovation is unknown. This thesis posits that Product Design methods such as UCD – User Centered Designing which focus on creative processes of generating ideas and concepts to meet user needs for innovation hold high potential.

2.5 User Centered Design and Usability engineering literature

The area of Interaction Design [Clemmenson et. al., 2008] has added to extending the philosophy and knowledge of the earlier discipline labeled as 'Industrial Design'. The ability of the user to use the product to fulfill needs has now emerged as a specialized area of research in design**.** User Centered Design (UCD) is a process that brings the user's needs into consideration from the beginning of the creative problem-solving stage in design morphology. The user is the center for all decision making. Central to User centered design is the morphology that is often labeled as 'Design Thinking' [Yammiyavar, 2010].
A comparison of traditional engineering product design method for innovation and the User Centered Design method employing creative design thinking principles has been attempted to bring out the novelty of the usability morphology. The new innovation model being proposed and validated in this thesis is based on the usability engineering morphology involving UCD.

2.6 Creative design morphology in product design to lay the premises for adopting UCD as a novel basis for innovation.

Methodology used by product designer is shown in below Fig. 2.11.

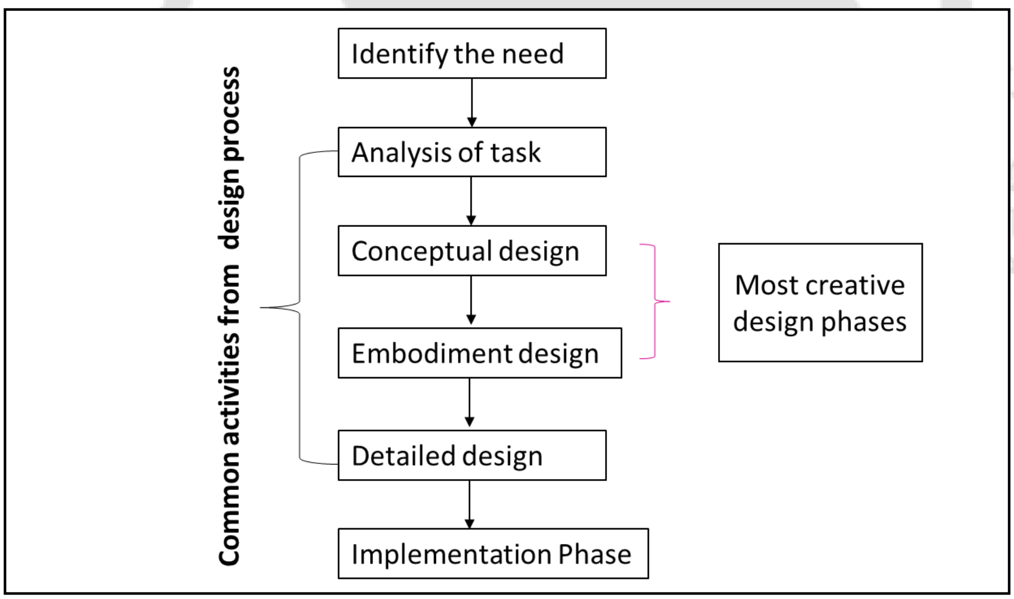


Figure 2.11: Most creative design phases in product design

The most 'creative' processes that occur in design are conceptual design and embodiment design phase [Howard et. al., 2008]. These can happen over the designers thinking and portrayed through their design sketches, often without the conscious knowledge of designer. While sketches do embed the creative solutions that define innovation, both designers as well as others are unable to recognize innovation from the designer's sketches. Thus, while creativity gets embedded in their concepts generated, there is no way to abstract its output as innovative. The opinions, answers and subjective judgements are the only available means of making quantification and is difficult. Therefore, it makes sense to break down the designer's tasks into micro steps to be able to abstract out. These micro steps incorporate as innovation, embedded in the features designed. This is a familiar practice followed in most of the design morphologies. Micro task analysis is a standard practice in operations management. While sketching and visualizing may be a part of a designer's skill of recording design thinking – the same may not be the core activity for engineers and business entrepreneurs in MSMEs. This is the gap in design morphology that this thesis aims to fill by developing an indexing tool based on micro analysis of product parts under value engineering principles. From these, templates can be developed that help establish relationships between a product's parts and thus help separate innovation inputs that get dissolved into the product. There is no such method to convert components of innovation resulting from the cognitive thought process of creativity in terms of indexical values. Our research aims in developing such method to identify a suitable innovation index.

2.7 Literature on Design Driven Innovation

To achieve innovation in organization, design approach helps considerably, but requires instant examination of the design methods and improvising the practices of the firm. Archer and Simon studies focused on design methods back in 1960s [Verganti, 2009]. Over the decades, a number of new methods, theories and approaches have been developed in design research.

Buchanan [1998], Franz [2000] have discussed the relation between innovation and design practices. Design council United Kingdom stated, "Design can help organizations transform their performance, from business, product innovation; to the commercialization of science and delivery of public services". Many European countries developed design innovation policies with the rise in MSME numbers. The Danish have 'Design vision 2020' with challenge led innovation. Good policies and vision makes design driven innovation to foster. China has 27 districts only for design, with all the modern facilities like prototyping, incubators, collaborations etc. Currently China is the manufacturing hub. A new shift in Chinese system is "Designed in China" instead of 'Made in China', [Lottersberger, 2012] promoting design as new strategy. Many MNCs adopted design principles into their practices and have become global leaders to name a few Apple, Dyson etc.

A study on Design driven innovation Fig. 2.12 [Verganti, 2009], describes it as: creating a new product that user never expected. It is not from market driven, data collected or any analytics, or any user needs but it is creating new markets. Current studies deal with incremental innovation and radical innovations, as many researchers and organization are involved. Design driven innovation pushes radical innovation to the new meanings. From where the meanings arise? Based on the researches, organizations should think on wider prospect to identify the new meanings, user adopts and accept that it is creating the meaning and it is made possible only by design driven innovation. Innovation in products is done by imbibing sense of things, which user never expected. It cannot happen in incremental innovation which many firms are practicing. This thesis posits that if radical innovation is pushed into a firm as a 'strategy', the total effect on a firm's profit margin increases significantly. As seen in the literature survey there are not many methodologies available to incorporate innovation as a strategy by MSMEs.

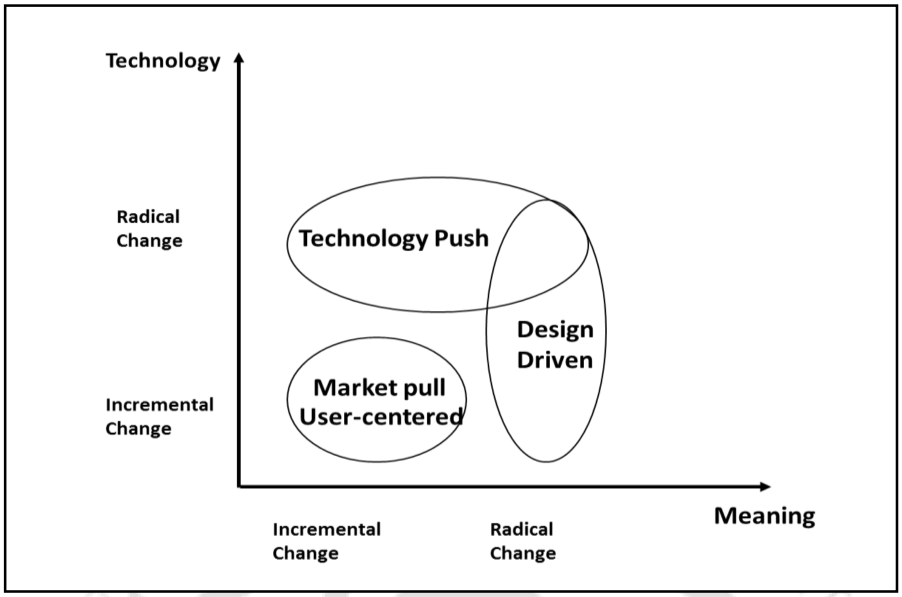


Figure 2.12: Innovation Strategies adopted and redrawn Verganti [2008]

The general innovation practices in organization is not readily visible and structured. User centered design and user needs can lead to the incremental innovation. When technology thrust meets, design driven meanings it leads to radical innovations. Thinking beyond users, socially and culturally can influence and create new meanings by the professionals called as interpreters. They can give deep understanding of products on how users give meanings. Design driven innovation in integration with design can give new meaning by producing breakthrough products. This approach and thinking is missing in Indian MSMEs. They need special training, skill sets and investment in designers etc. our research focuses on providing a method to get into design thinking and producing more value added products. Currently there are many design clinics established in India, but the lack of communication and lack of design thinking has slowed down the path for innovation. But the researchers are finding new ways to achieve innovation, especially through usability or UCD and design driven innovation as promoters of innovation.

In this thesis it is posited that UCD approach and the "user needs" themselves can lead to incorporating incremental innovation. When technology thrust meets design driven meanings, it leads to radical innovations. Thinking beyond users, socially, culturally can influence and create new utility meanings by professional designers. Design driven innovation can give new meaning and insights by producing breakthrough products resulting from reinterpreting meaning in social and lifestyle contexts. Currently in a country wide government funded experiment there are many 'design clinics' established in India for MSME [Design Clinic Scheme for MSMEs 2011, National Institute of Design project] to improve the comprehension and integrating design as value adding process for MSMEs. But lack of awareness and lack of design thinking as a strategy amongst MSMEs continues to prevail despite such massive efforts.

A popular Hindi language term called 'Jugaad/Jugged' is often found in Indian popular media. It is a Hindi language term and is not found in southern parts of India or is unknown in non-Hindi language regions of India including the southern parts. Jugaad is loosely translated as 'contraption put together from parts at hand'. At best it is a romanticized version of the word innovation. Often products that are touted to be a result of Jugaad are raised in status as 'wonderful examples of what

Indians can do without much resources'. Most of the products resulting from the Jugaad approach are of very low quality, unreliable and inefficient from all respects. Other countries call such innovations as frugal innovations. An example of Jugaad are given below in Fig. 2.13.

Figure 2.13: Examples of Jugaad, Coffee making with pressure cooker and pumping water by bike

At best, Jugaad approach can be a starting point for idea generation. Jugged products do have possibilities of being developed into full-fledged innovation. This would be possible, if a systematic method of adding value by measuring the incremental improvements is brought into the jugged schema. There are no models for upward movement of transforming Jugaad ideas into commercially sale-able innovative product. Attempts by non-governmental organizations (NGOs) such as SRISTI [Honey bee] have been encouraging grass route innovators and jugged contraptions but their total efforts seem to indicate marginal gains. Micro enterprises to whom jugged appeals do not have better models for innovation which is a gap that, this research takes into consideration.

2.8 Making UCD and Usability as a novel basis for the development of an innovation metrics model/framework

UCD is a process that brings the user's needs into consideration from the beginning of the project. In general product design morphology, the focus is on the perfect product being manufactured. The user is the target and the consumer of the product. Hence, a user does not normally figure in engineering design morphology. Engineering design is therefore product centered design and not user centered. There are fundamental differences in design morphology as practiced in engineering design and as practiced in creative design.

If the focus is shifted from product centered design to UCD or user desired/utility led designs, then there is scope for adding value or innovation in products during product design phase. Currently the focus and research is on usability, applied to Software, Websites, IT and C related products dealing with Human Computer Interaction (HCI) [J. Nielson, 1992; Shackel, 1981]. UCD and HCI, ideology gives primarily more attention to the human factor and ergonomics. The usability aspect is also essential in a way to be close to the user [Rodriguez et. al., 2007].
The user centered design method is governed by 4 fundamental axioms of design as [Yammiyavar, 1993] mentioned below:

1. User is the only constant in a system and all other variables are dependent on each other.
2. In conceptualization phase users are the initial starting point for all designs.
3. For all design considerations users are the final datum of reference.
4. User is the fundamental unit of any scale developed for measurement.

As the user is the evaluator based on the user's needs, adopting UCD will result in higher degree of innovation. In the book "The Design of Everyday Things", Norman [2013] has emphasized fulfilling needs of the user being more important than aesthetics while designing the products.
When a product is designed it is important to utilize the usability standards (ISO standards), leading to a good experience of product and it is the job of a designer to do so. Usability and UCD are the core concept of industrial design from the past two decades [Tom, 2003; Ulrich, 2003; Neville Stanton, 1998].
Usability standards ISO 9241 defines usability as 'The extent to which a product can be used by specified set of users to achieve specified effectiveness, efficiency and satisfaction in specified context of use'. Usability is the measure of the quality of the user's experience while interacting with the product.
Designing with user involvement i.e. user is actively co-collaborating in the design process, often leads to better user insights being incorporated into the product resulting in value addition through usability and utility. Several methods in UCD have been mentioned in published literature [Dix, 2009; Rogers et. al., 2011]. These are - Contextual Design, Content analysis, Focus group protocols, Empathic Design, Persona, Scenarios, Essential Use Cases, Card Sorting, Participatory Design and Protocol Analysis to name a few.

Usability Engineering (UE) is the process of deriving, specifying, measuring, constructing and evaluating usability features in a product or system. The goals of usability engineering are 5 E's and they are as follows: Effective to use, Efficient to use, Error free in use, Easy to use and Enjoyable to use.
Usability has constituents such as Visual Quality, Semantics, Physiognomy, all of which are related to the term 'Aesthetics' in Design. Physiography or physical features and Ergonomics includes safety, comfort, utility etc. Functional aspects that manifest themselves as anatomy of a product include parts, configuration, materials, production, structural properties etc. The three aspects – Aesthetics, Ergonomics and Function define a products design space [Yammiyavar, 1993]. Usability and Design are the two faces of the same coin. Without usability, design (in the traditional sense of the word) alone cannot achieve higher levels of innovation. In any product usability must be induced in the designing phase as stated in ISO standards 9241, IEE 90, ISO 13407.

2.9 Making Design Space theory as basis for measuring user driven inputs to innovation

Design Space is defined as combinatorial space generated by set of parameters, which are also the operands (Aesthetics+ Ergonomics+ Function=1, Design ratio) [Yammiyavar, 2004]. It is the base for developing a proposed fractal triangle of innovation, which is discussed in further chapters.

Design Space is as depicted in Fig. 2.14 and Product Proximity Factors – (PPF) [Yammiyavar, 2004], are intended to indicate the product's proximity to the user in terms of quality interaction. User being at center, the highest level of innovation which is considered as the ideal product having value of ‘1’. Such highest level of innovative products does not exist as it is an idealized state of a perfect product in all respects. Any product can reach the value towards ‘1’ but is likely to always be lesser than ‘1’ as user needs and aspirations as well as technology keep evolving rapidly. An explanatory example would be ‘Contact Lenses’. Earlier contact lenses were thick and irritating to use. They were essentially glass lenses miniaturized and manufactured using softer polymers. So compared to spectacle glasses contact lenses definitely tended towards zone 1 However, they have not reached an ideal perfect product. The latest development in contact lenses are soft very thin lenses that have reduced eye irritation. Their usability is a result of innovation in materials and manufacturing technology but their innovation was forced by the user’s irritability with earlier thick contact lenses. Yet these contact lenses have potential to reach an ideal design state. However, now researchers are trying to change the DNA, at the genetic level (stem cells) which can correct the eyes defects in one’s lifetime. If successful one can declare it as highest level of innovation, falling under Product Proximity Factor zone 1 (PPF) as shown in Fig. 2.14. As we move away from center/user the interaction with product goes down and are called PPF zone 2, watches, shoes, clothes are examples of this zone. And it continues till PPF zone 5 and above. Maximum products that are used by user in their daily life fall under PPF zone 2 and 3. To achieve innovation in products one needs to come closer towards the user. This is the underlying philosophy of User Centered Design –UCD [Yammiyavar, 2004].

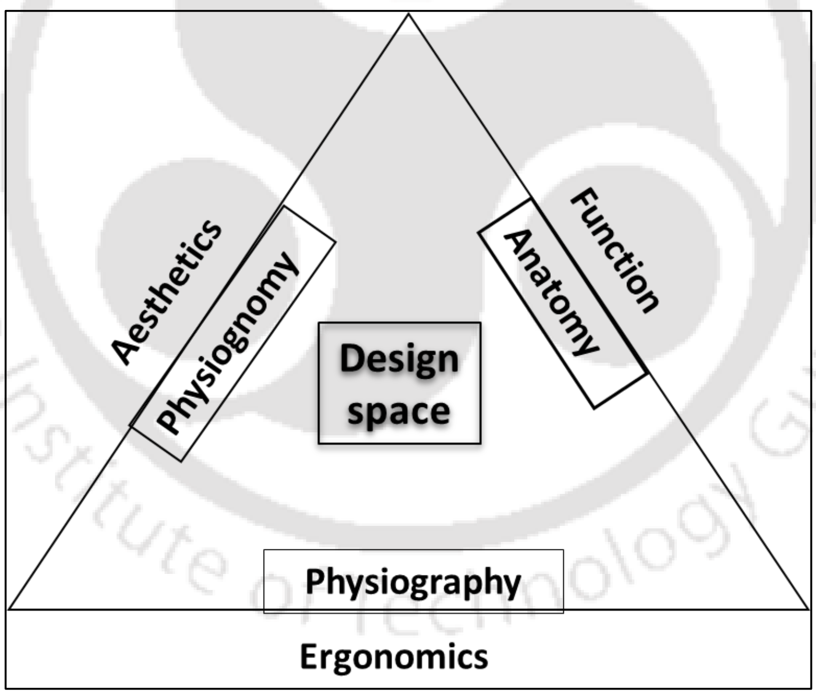


Figure 2.14 a: Showing design space adopted from [Yammiyavar, 2004]

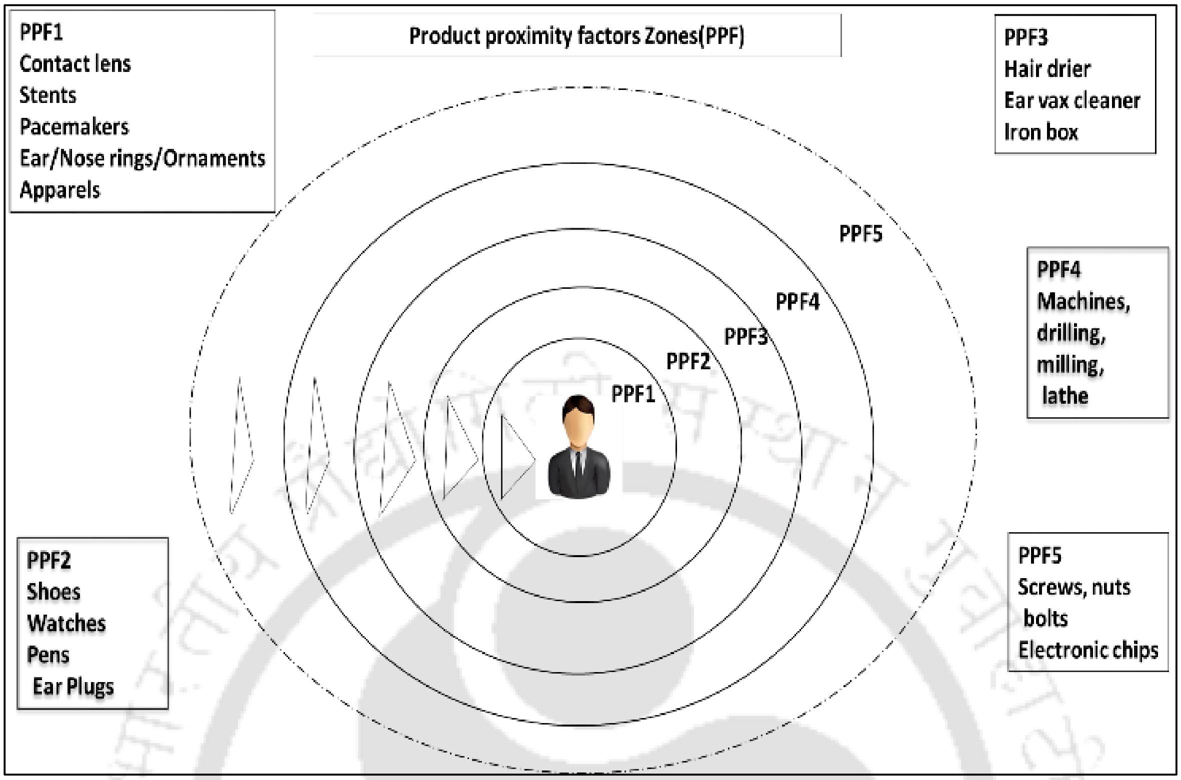


Figure 2.14 b: Showing PPF zones adopted from [Yammiyavar, 2004]

Maximum number of products used in our daily life fall under PPF zone 2 and 3. Majority of similar products manufactured by the MSMEs would fall under zone 2 or 3. From Design Space concept and Product Proximity Factors – (PPF) [Yammiyavar, 2004], around 450 plus products were analyzed to understand the interaction time of each product with the user. The same have been categorized as PPF zones. In which '1' being the highest level of interaction and it is ideal. As the interaction time with product is lesser the product moves away from the user (PPF zone 4, 5). For the study, 100s of products were visually analyzed and observed. Most of them fall under PPF zone 2 and 3 (day to day products, from pen to computers, utensils to electronic gadgets).

In this thesis it is posited that if one were to be able to analyze such products (falling under zone 2 and 3) manufactured by MSMEs for their degree of 'fitment' in zone 2 & zone 3, it would be possible to identify design deficiencies. Further these functional deficiencies or short-comings could yield insights to designers as to the particular spots or features in a product's subassembly that have potential for design improvement. One can then maximize the innovation effort if one has a means of comparing two creative solutions that emerge through design thinking process attempting to eliminate defects or add value. In this thesis this method of value addition has been adopted.

2.10 A survey and evaluation of tools and techniques in Product Design Aiding Innovation

Currently there are a host of tools and techniques employed in product design, which were developed over the last 50 years. Initial observations reveal that these tools are more suitable for companies and organization whose turnover is higher than MSMEs. Based on the interviews and discussion with MSMEs, it was observed that they did not follow the structured approach i.e. different teams for different tasks which makes them utilize many tools and techniques. It is difficult for a single person to adopt, act and practice. Tools like QFD, TRIZ, Taguchi method, Six-sigma etc. require high investment, training and guidance and this is a major constraint for MSMEs. Some MSMEs are not in a stage to upgrade themselves in terms of automation and high end machines due to high initial investment. This is one of the main reasons they are reluctant to adopt new trends and technology. MSMEs are focusing more on producing products and sales rather than the design. The companies and organizations whose turnover is higher than MSMEs can utilize any tools and technique. They have their own R and D team and can follow a proper design cycle. It is posited here that there is scope for developing a set of tools and techniques by adopting best practices from available ones to be useable by MSME at their scale and resource levels.

The specific end goal was the identification of the most appropriate and best suited design methodology tools from the available ones in the literature. Factors that drive the innovation activities in a small emerging economy and comparison with the findings from developed economies were carried out by Sonja et. al., [2009]. The study gives an insights of the major obstacles to innovation as internal and external factors in developing economies. Internal factors include firm age, proportion of highly qualified employees, internal R & D etc. External factors include collaboration with other firms, link with universities, national and international markets. In addition to this, market scope was discovered to be a very important factor in both product and process innovation. The study also emphasizes that implementation of corporate changes has positive impact on radical product innovations and new organizational structure have positive effect on incremental innovation. Unfortunately, even though the MSMEs are major players in the economics of the developing countries. But they are not in a good position as the bigger industry to make innovation practices as part and parcel of their day to day strategies. This need gap of MSMEs has been addressed in this thesis by developing a framework or model for facilitating in-house innovation.

Innovation tools and practices used by well-established industries such as SCAMPER (Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse); 5W1H (What, Where, Who, When, Why, How), and TRIZ (Theory of inventive principles); Brain Storming; Functional Analysis etc. have been studied by several researchers [El-Sharkawy & Schmid, 2011; Changqing et. al., 2005; Chulvi et. al., 2012]. Most of these papers compare the degree of creativity in design resulting in innovation using different tools. Value engineering and QFD (Quality Function Deployment) is combined to have optimum design output along with functions and engineering requirements as highlighted in the paper by Luis Ramos da Silva et. al., [2004]. The MSMEs are not practicing any of such methods or employing any of these tools specially in unorganized sector.

The ability and innovative capacity of MSMEs varies significantly depending on the sector, size, focus, resources, regions and the business environment. Aspects such as factors determining technological innovation, constraints for technological innovation in MSMEs and its major issues in Indian MSMEs is focused by Bala Subrahmanya, [2012]. The study also focuses on MSMEs innovations in India versus U.K. and Japan. Murthy et. al., [2008] discussed and proposed a new model having better decision making and product life cycle considerations. It is posited that internal factors such as use, usefulness, time, cost, and external factors project nature, organization, skills, culture etc. have been put forward by Maylor, [1997] in NPD techniques.

Yeh et. al., [2010] discussed about the appropriate tools and techniques that are suitable in NPD stages and their impact. Sokovic et. al., [2009] have focused on seven basic quality tools such as, Flow chart, Pareto diagram, Check sheet, Control chart, Histogram, Scatter plots, Cause-and-effect quality tools for (continuous improvement in processes) PDCA-cycle, Six Sigma (DMAIC) and Design for Six Sigma (DMADV) methodologies. Nijssen & Frambach [2000] have emphasized on detriments of accepting NPD tools as QFD, Brainstorming and Delphi method etc. The product innovation aiding tools such as SCAMPER, 5W1H, Brainstorming TRIZ are posited in Changqing et. al., [2010]; [Creatingminds.org]. Creativity and innovation in products are highlighted along with the above said tools in [Changqing, et al., 2010; El-Sharkawy et al., 2011; Chulvi et. al., 2012]. Luis Ramos da Silva et. al., [2004] have showed that combining of the tools and techniques will enhance the performance. Murthy et. al., [2008] focuses on the different models available in the NPD stages and proposed a new model that is better suited in decision making of product performance and specification. Product Life Cycle (PLC) underlines such models. From this literature study the most appropriate and frequently occurring techniques and tools were identified on which an in-depth heuristic analysis is planned to be carried out.

Lutters et. al., [2004] have presented an audit of using tools based on the performance of creativity and decision making as used in the design field. Keeping designers in view - tools and techniques have been characterized with respect to their industrial application. An exploratory investigation on the role of quality control tools in product development have been identified by Thia et. al., [2005].

Based on the literature study an attempt is made to characterize distinctive tools and techniques that have influence at different stages of product design and development. And the Table 2.5 represents the study. This categorization is intended to examine which of the available tools could be useful for MSMEs.

It is observed that Indian MSMEs are hesitant to adopt or try out new models into their practices as they are not conversant with these techniques nor do they find them relevant. MSMEs in India are market driven and not product driven as noticed by the sheer number of new products continuously being introduced by the Chinese MSMEs. The new tools will not be of much use to the Indian MSMEs unless the tools and techniques are easy to use and are meaningfully tailored, affordable to the Indian MSMEs and their practices. Product designing from scratch is rarely adopted at Indian MSMEs. Designs are either reverse engineered or reproduced from existing designs which was concluded based on the content analysis (Chapter 3).

2.11 Use of Design Stages and Morphology for categorization

Product development stages are not followed by many MSMEs as time, money, effort and cost increases. Different stages of product development have been adopted from Chaturvedi, [1997] and represented in Fig. 2.15. The Table 2.5 gives an overview of tools and techniques that have been classified and are used in different stages of product development [Tague, 2005; Defeo, 2010].

Figure 2.15: Shows the product development stages

Table 2.5: List of Tools and techniques at different product development stages

Idea generation and Idea screening	K J Analysis, Brainstorming, Brain drawing, Brain writing, Fishbone diagram, Delphi method, Breakdown, Lateral thinking, Crowd slipping, How-How diagram, 5W2H, Chunking, TRIZ-Contradiction analysis, Value Engineering, Mind mapping, Concept screening, Story board, SWOT analysis, Positive and negatives, SCAMPER etc.
Identify customer needs (User and Usability)	QFD, Kano model, Pugh matrix, Surveys Focus Groups On job/ Usage observations Interviews, Gathering customer information, internal surveys, Customer complaints, Customer sacrifice gap etc.
Concept development and testing	Concept screening matrix, Function Diagram, Concept combination tables, Decision matrix, Concept scoring matrix, Concept description sketches, Concept classification trees etc.
Root cause analysis/cause and effect	Fishbone diagram, Why-why diagram, Fault tree analysis, FMEA, Pareto charts, Force field analysis, Scatter plot, Is-Is not matrix etc.
Product Development (Product specification, System level design, Detail design, processes)	Specification lists, Needs metrics-matrix, Benchmarking charts, Bill of materials, Prototyping, Geometric layout, Assembly drawings, Material selection, Design for manufacturing, Design for assembly, FMEA, Design for X, PHA, DFE, Taguchi methods, Pokayoka, Value engineering/analysis, Design Audit Control chart1, 2, 3, Quality cost audit, PDCA, PDM, JIT etc.
Project management and planning	Design structure matrix, CPM/PERT, Activity diagram, Gantt Chart, Four field analysis, Estimation, Tree Diagram, Risk analysis, How-How diagram, Postmortem project report matrix diagram, Checklists, Potential probe analysis, CAD/CAE/CAM etc.
Decision making/Evaluation	Concept screening, Decision tree, Criteria filtering, Estimation, Swap-sort, Important-urgency map, Matrix diagram, Prioritization matrix, Tree diagram, Voting/Multi voting etc.
Data analysis	Box plot, Check sheet, Histogram, Control chart, DOE, Pareto1, 2 3, Scatter diagram 1, 2, Radar chart, Z chart, Regression analysis, Normal probability plot, Sampling, Performance index etc.

2.12 Mathematical theories as basis for developing innovation metrics

In the mathematical field of graph theory, a bipartite graph is a graph whose vertices can be divided into two disjoint sets and (i.e., and are each independent sets) such that every edge connects a vertex into one in vertex sets and are usually called the parts of the graph. Graph theory has been applied across many disciplines to analyze the whole system, identify and develop the metrics, generating an indexical value.

Based on the graph theory, a digraph and permanent metrics were developed to prioritize the parameters that influence the metal stamping layouts [Singh & Sekhon,1996]. Even though the problem is core mechanical one but number of parameters involved are high, just like innovation and product design. Similar study by Rao & Gandhi, [2002] was done to evaluate and calculate the machinability index. Graph theory and matrix approach was utilized for selecting material for an engineering component by calculating 'material suitability index' [Rao, 2006]. Groover et. al., [2004] discussed on applying digraph method to TQM for identifying the factors influencing TQM and developing an indexical value for comparison amongst the parameters. Graph theory and digraph are well established with system approach. Same was applied in case of mechanical and hydraulic system to analyze the FMEA (Failure Mode and Effects Analysis) [Gandhi & Agrawal, 1992] positing that this methodology can be utilized during design stage as well as in a working condition.

Evaluation of parameters such as performance, serviceability, aesthetics, reliability, features, conformance of an automotive vehicle was done by Venkatasamy & Agrawal [1997] using graph theory and digraph method. A graph theory based method named as 'Linkograph' as propagated by Goldschmidt, [2014] has been used as the main instrument in experimentation and is explained below.

2.12.1 Linkography - an overview

As per Simon [1982], to design, is to devise "courses of action aimed at changing existing situations into preferred ones". Design is appropriately characterized, and is the whole process over the entire spectrum of domains required for any result. Domains of design are product design, industrial design, graphic design, interaction design, system design, usability engineering and many more which fulfills the needs of humans in a better way. Design is not a plan of action and designing a product, but it is a thinking and imagining of new futures for solving problems or creating entirely new product. In achieving this, we have design theories, design thinking, design management, which will gear up creativity and innovation to the next level. Out of available methods of understanding the analysis of the design process, Linkograph [Goldschmidt, 2014] is one method which we are using in our research. It involves the design thinking, cognitive psychology and protocol analysis to generate any purposeful observations. In developing linkographs, design elements and their variables are the foundation for building innovation model. Each design element is checked for its relation and marked as nodes, and 'moves' are design-moves. From the linkographs, we can measure the link index and critical moves.

2.12.2 Linkography method

Design integration at the subconscious level is comprehended as emerging from an exploration that consist of cycles, the design acts of ideation and decisions. These design acts gradually emerge into a creative design proposal or solution. The design acts in question are defined/characterized as design moves and observe that links act is interconnected to give end result or best fit of decision.

A linkography is essentially a modification of the matrix, even though few researchers still want to adhere to matrix representation [Van der Lugt, 2001]. A digraph without the arrowhead is used in the linkography. It was chosen due to the fact that it accentuates the arrangement of the links in a network of design act/sparks. The network of links makes the perception of the act convincing and logical and this portrayal is better when we emphasize the ideas as nodes rather than just a line.

The number of links generated is not fixed, as it is a cognitive process and it varies at each point of design act with micro level thinking. However, for the study, we have identified some design elements which will boost the innovation. A few moves produce more links than others as example shown in Fig. 2.16. The links may be back links or fore links or combined both links being the types of moves. The critical moves which are richly linked to back and fore links are the most important moves. Links are the quality of process indicators and Critical Moves (CM) are of special significance.

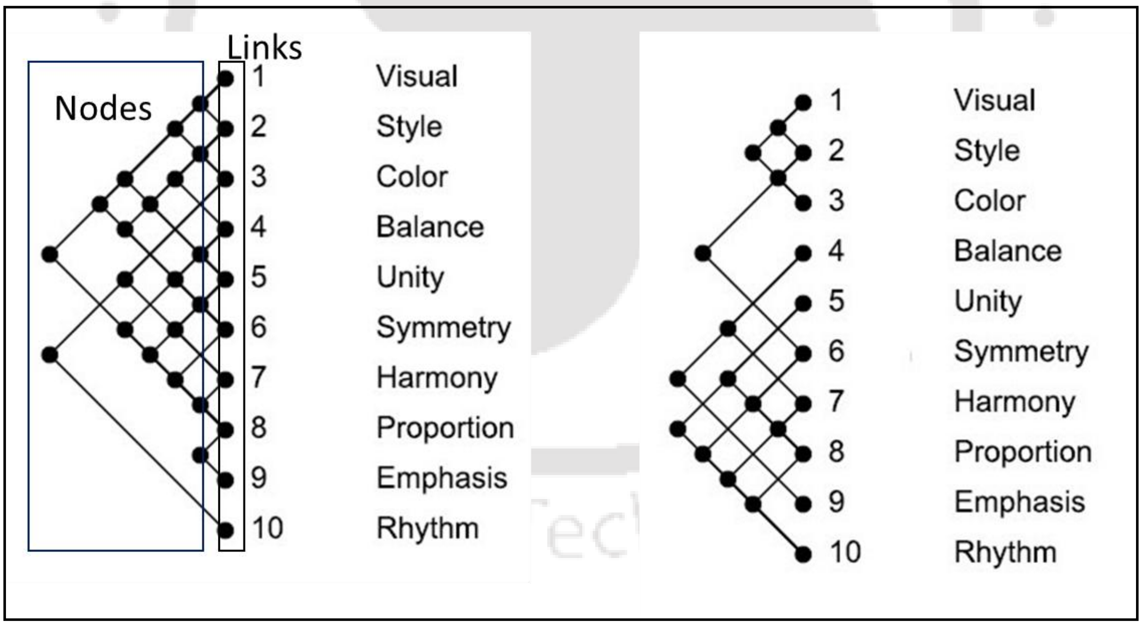


Figure 2.16: Showing the example of linkograph and its plot

Question arises, what makes a move critical? It is purely depending on the depth of analysis or the number of overall links. Depth of analysis pertains to the susceptibility of the researcher to establish the relationship links in a design act.

The link index is the ratio between the number of links and the number of moves that generate them in a linkography or part thereof expressed as a proportion. The link index depends on the total moves and nodes of an act. Design thinking is reflected by linkograph in a logical way. In a linkograph, if more number of chunks are present, then the design thinking or design act is moving systematically and lack of chunks will lead to the other problems of the act.

Based on the design elements listed, fractal triangle of innovation and design space of our initial study leads the input along with user ratings to build the linkograph for the identified products. In developing the linkograph, the logical reasoning leads to establish the relationship between the design elements. Link index, Link span, critical moves, the number of back/fore links are calculated quantitatively. The generated/procreated linkographs are shown in further discussion.

2.13 Currently available Innovation models and their drawbacks

The available innovation process models and measurement frameworks are listed and discussed in brief, namely diamond model, Innovation funnel, Innovation value chain, OSLO Manual [Mortensen & Bloch, 2005], manual of innovation measurement frameworks. Best firm's innovation methodologies, innovation audit/management tools were identified from the study of Gamal et. al., [2011] such as Inno-CERT, Inn-Biz assessment, NESTA, IMP^{3}rove-Europe Innova, Innovation radar, innovating for growth etc. which are discussed further in the section.

There are many innovation models available in different sources as policies, handbooks, innovation management research articles. Rogers, [1962]; Cooper, [1986]; Rothwell, [1994] models are the very first models of innovation. But these were the building blocks for the generations of new models, Eveleens, [2010].

Van der Ven et. al., [1999]; Nooteboom, [2001]; Mulgan and Albury, [2003]; Tidd et. al., [2005]; Andrew et. al., [2007]; Hansen and Birkinshaw, [2007]; Jacob and Snijders [2008] all have worked on the development of innovation models with the focus being product, process, service innovation. Their study was based on prior research, case studies, experience and empirical research. The type of firms was private having large size or multinational companies. Tidd et. al., [2005] and Jacobs and Snijders, [2008] emphasized both on large and small firms. Rothwell, [1994] and Verloop, [2004] focused on the radical type of innovation in products and services, the rest of the models were not stated as radical innovation.

Some of innovation metrics are based on the innovation inputs such as R&D, expenditures, science and technologies, capital and technical intensity, etc. which are called the first generation (1950-60s) [Milbergs & Vonortas, 2004]. Some of the innovation metrics are based on the innovation outputs as patents, publications, products which are called as second-generation output indicators (1970-80s). Gittleman, [2008] showed that patents as the metrics for innovation is very much limited for MSMEs. Booz [2005] showed that there are not many relationships between R&D, business success in terms of innovation. Benchmarking, indexing and innovation surveys fall under third generation innovation indicators (1990s). For multinational companies' country level innovation, European Union uses OSLO manuals [Mortensen & Bloch, 2005], European community innovation survey (CIS4), Innovation score board (EIS). The fourth-generation process indicators (2000) are knowledge, network, demand, cluster, management techniques, risk etc. Fifth and the current generation of innovation indicators talk about the technology strategy, design for manufacturing, new technology adoptions, quality and performance, and user requirements. By generation-wise observation indicators of innovation are continuously getting added up. Current innovation trends talk on UCD, Usability and design based on the cited literature and our thesis intended to work on this, specifically targeting MSMEs.

The Diamond model proposed by Tidd, [2006] has five dimensions of innovation assessment. Which include strategy, process, organization, linkages, learning. An assessment will be done by a set of questions. In the Indian context, there is no fixed structure for the MSMEs and there is no strategy, learning and different levels of organization, and culture. As seen from the Government report on MSMEs, there are 15.64 lakhs MSME that fall under registered and 198.74 lakhs of MSME that fall under unregistered sector [MSME annual report 2017]. The unregistered MSME number is large, these enterprises do not follow any fixed path of design, organizational structure, strategies, R & D etc. (When we visited a MSME, we found that a group of 5-6 people are managing all the work, designs were brought from other place and manufactured. For instance, an umbrella manufacturer works for 6 months and makes a variety of umbrellas and sell them throughout the year) Their focus being on profits and margins. Therefore, this makes it difficult to adopt it in the Indian context.

Innovation funnel is another model having nine elements such as portfolio management and metric, research stage, ideation stage, insight stage, targeting stage, innovation development stage, market development stage and selling. The adoption of these steps in Indian MSMEs becomes a difficult task due to lack of knowledge, time consuming processes, market oriented product but not the user needs. Similar thinking of MSMEs in case of innovation value chain was proposed by Hansen and Birkishaw [2007] in HBR article, it has 3 phases, i.e. idea generation, idea development and diffusion of developed concepts.

Balanced score card model, was proposed by Kaplan & Norton, [1996] which has translated vision and strategy of a firm into set of performance measures i.e. customer, financial, internal process, learning and growth. Ivanov & Avasilcai, [2014] have analyzed 3 case studies on this method and applied it to measure the innovation process. Here the case studies concluded in organizational goals with a major focus on R&D, return on investment, sales and profits. This method of balance score card will not reveal the innovation independently.

OSLO manual presents the insights from various theories of innovation and many audit tools have been developed over the years. It focuses on the demand, innovation in the firm, links between the other firms and research institutes. When we take Indian context, very few of them are linked with research institutes. Same old practices in the firms and the lack of technological upgradation etc. makes Indian MSMEs to look for different tools, techniques or method. Malaysian Government uses the tool Inno CERT and Korean Government as Inno Biz for international benchmarking to bring innovation in their firms. This can be studied and based on our needs, we can develop our own tool. In the United Kingdom there is a National Endowment for Science Technology and Arts as NESTA, which pushes the early stage companies towards the innovation. They brief and encourage to add innovation into their practices. Some more innovation audit tools are IMP^{3}rove-Europe Innova based on the dimension suggested by Kearney, [2008]. The Innovation Radar is a tool, developed by the Kellogg School of Management's researchers Sawhney et. al., [2007] that focuses more on the bigger organizations. The key features of the above innovation models are present in Table 2.6.

Table 2.6: Innovation process models and their implications adopted and modified from Eveleens, [2010].

	Based on	Innovation Type	Firm size	Incremental or radical
Cooper and Kleinschmidt (1986)	Recent theory and practice	Industrial manufacturing product innovation	Fairly large with an own R&D department and a distinctive senior management	Both, but leaning towards radical
Rothwell (1994)	Prior research	Product	Fairly large	Not explicitly stated, but tendency to radical
Van de Ven *et al.* (1999)	Large empirical study	Product, process, Services	Large	Not explicitly stated, but tendency to radical
Nooteboom (2001)	Theory	Product, process, Services	Large and small	Both
Mulgan and Albury (2003)	Prior research + some case studies	Services	Large	Both
Verloop (2004)	Experience	Product, process	Large	Radical
Cormican and O Sullivan (2004)	Model based on theory, verified in practice.	Product, technology	Large Multinationals	Portfolio of different novelties
Tidd *et al.* (2005)	Empirical and theoretical research	Product, process, Services	Large and small	Both steady state as well as discontinuous innovation
Andrew and Sirkin (2006)	Experience and empirical research	Product, process, Services	Large	Not very explicit, but leaning more towards radical
Hansen and Birkinshaw (2007)	Based on empirical experience of the authors	Product, process, services	Large Multinationals	Not very explicit, but leaning more towards radical
Jacobs and Snijders (2008)	Theoretical and empirical research	Product, services	Large and small	Emphasize that most Innovations are incremental

By examining the above innovation metrics, methods and tools also from other publications, we highlight that the major gaps identified are: There is no perfect tool which can suit Indian MSMEs, the above discussed tools, methods and theories will give innovation values in the form of country level, organization level and firm level. But there is no such single tool which can measure innovation index at product level, which is the major gap in innovation models and measurement at the product level. Given two products of same family, how can a designer or user tell which is innovative? How innovative is the product? Our research work tries to answer these questions by developing an innovation matrix for MSMEs in the Indian context.

2.14 Inferences of Literature review chapter

We have gone through numerous reports, papers, articles, books etc. under each segment as shown in chart (Fig. 2.17) and identified the gaps and formulated basis of our theoretical approach to the research topic. We evaluated a number of concepts, definitions and tools to examine which of them can be used in our proposed frame work or model for innovation targeted to MSMEs. We identified shortcomings of existing practices and their unsuitability to be used in the MSME case.

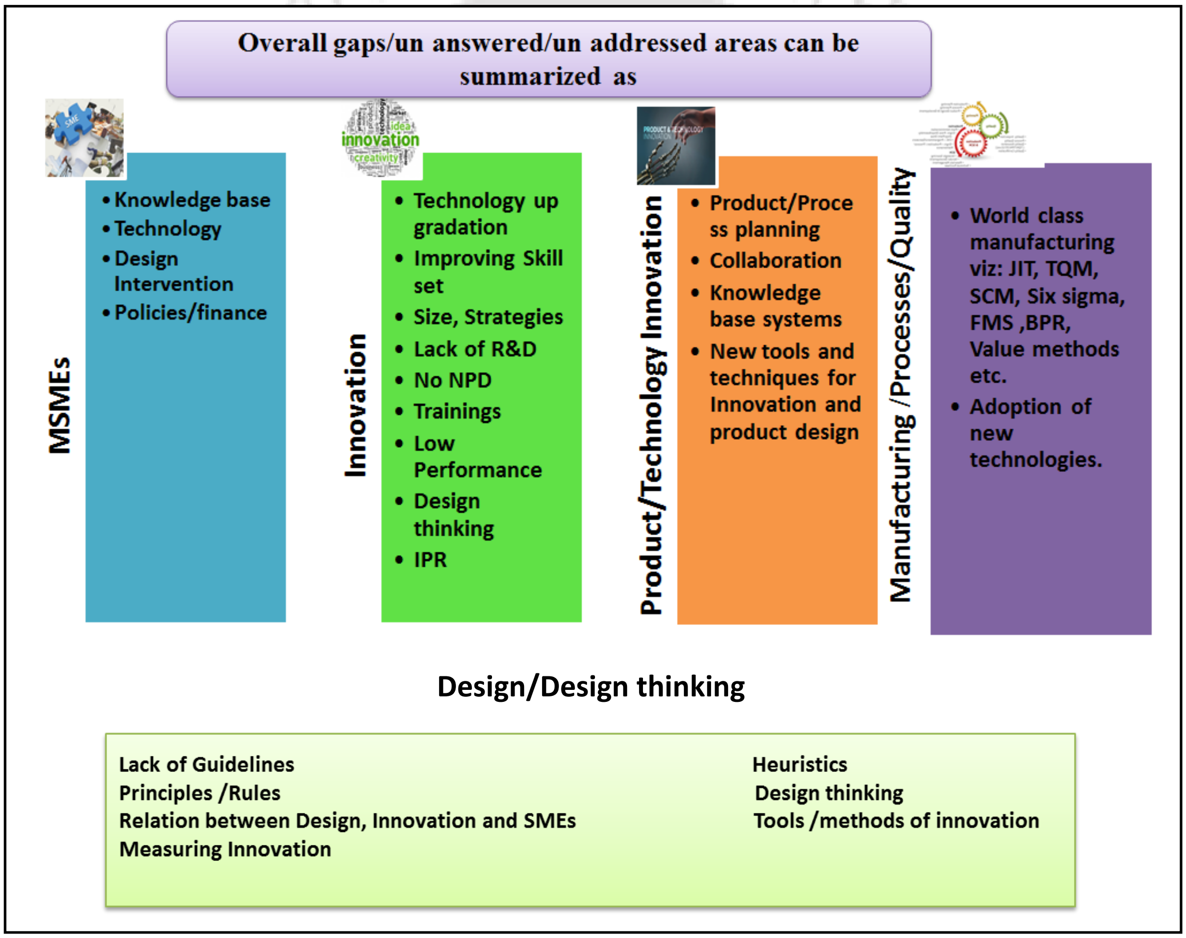


Figure 2.17: Overall literature outcomes

The literature survey and the gaps observed leads us to questions that we intend to take up in the next chapter. Some of the questions are:

- How to innovate effectively and quickly?
- Where to focus during product designing phase to enable value addition?
- What are the variables that influence innovation?

- How to measure innovation and metricize comparative benefits?
- How to compare competitive products for their innovative content?
- Can we develop a frame work or model that attempts to answer these questions?

Based on the study and discussion with the MSMEs, there is a knowledge gap, in the current scenario. The lack of design intervention, low risk taking in terms of finance or exploring new ideas and probably some Government policies have led MSMEs to be on a slower trajectory of innovation. This is the gap one need to address within the constraints of resources available for MSMEs.

Both technology upgradation and employing quality tools requires initial investments which cannot happen without skill upgradation. The size of firm also matters in adopting R&D activities. MSMEs are not actively adopting design thinking and IPR as much as they should.

Some MSMEs follow old traditional methods as in case of brass artefacts (Hajo in Assam, Bidar in Karnataka). These can benefit by, new methods and techniques in developing new products.

Summary of chapter 2: The literature surveyed on MSMEs and innovation in product design have been presented. MSMEs' practices, problems in aiding innovation and need of innovation measurement in product design has been discussed. Available literature on product design, innovation models, theories, innovation measuring tools and techniques have been reported along with their suitability and drawbacks. Available tools and techniques in product design promoting innovation by other researchers has been outlined and important tools that can be utilized by the MSMEs have been evaluated heuristically. The survey features the results of the previous investigations and reports the gaps for further exploration/research. Broad research questions based on the gaps in the areas of innovation and product design have been raised. This leads us to the next chapter wherein detailed methodology and experimentation planning has been discussed.

Chapter 3

3. Research Methodology

Abstract: This chapter outlines the methodology of the study carried out. The design of analysis experiments, audit procedures, description of sample sizes and participants, product cases chosen for the study along with surveys conducted for the research is explained to give an overview of the stages and structure of the design behind the research work.

3.1 Introduction

In the previous chapter, review of published research work related to product design, creativity, innovation, definitions and approaches such as UCD, current practices of MSMEs and relevance of design thinking etc. was presented. The need for innovation with comparative metrics for MSMEs was identified. Based on this need, our research objective is to develop an innovation frame work that can be adopted by Indian MSMEs. For this, one needs to start with identifying all the variables that influence the innovation process in product design. Along with this another objective is to develop a measure or metric for innovation such that degree of innovation between two products can be compared relatively. There is also the need for validating the proposed frame work. We start this chapter by reiterating the objectives followed by overall view of research stages.

3.2 Objectives of the research study

The main aim of this research is to develop a relative innovation index for the products that are manufactured by Indian MSMEs and provide a framework using which innovation can be measured and incorporated during product designing morphology. Following were the main objectives of the research:

Ob1: To develop a framework for innovation that can be adopted by Indian MSMEs.

Ob2: To propose a framework that can act as morphology for incorporating Innovation by MSMEs right from the product conceptualization stage.

Ob3: To develop a measure or metric for innovation such that degree of innovation between two products can be relatively compared.

Ob4: Conduct validation of the proposed model by the end users of the model (MEMEs).

3.3 Questions that motivated the Research

Having described and set the background in which this thesis is contextualized in the previous chapters, we state the questions that prompted taking up this research are as follows:

RQ1. Can the MSMEs be provided with a practice methodology, using which they can add value to their products through knowledge of designing?

RQ2. What are the current practices and levels of innovation in MSMEs, are they proficient and beneficial?

RQ3. How to select product concepts that have higher innovation content while they are conceptualized during their designing phase?

RQ4. Can we develop a comprehensive framework which can potentially develop into a model for achieving, comparing and indexing innovation during a product's design phase for the use by MSMEs in-house without the need of outsourced expertise?

The above questions raised also become markers or stages defining the exploration methodology adopted in this thesis which is depicted in Table 3.1.

Table 3.1: Overall methodology followed in reference to the objectives

Stages	Questions	Research tasks/methodology
1	Preamble	Preparation for research: -Extended literature review -Identifying the research gap -Building the objectives
	What are the design elements that designer/MSMEs need to consider while in product design phase to cater innovation?	-A frame work of innovation for the use of MSMEs -developing a model for innovation -Identifying all the variables influencing to aid innovation in product design phase -Developed based on the analysis of literature review
2	What are the current levels of innovation practices in MSMEs, sufficient and beneficial as compared to the other countries?	-Available innovation models and their suitability to Indian context- From Literature **- A questionnaire based cum practices in 10 MSMEs/enterprises which is discussed in 3.6 below**.
	How and what methodology to carry product analysis during Design audit?	Flow charts have been developed to carry out product analysis. It consists of Fishbone diagram, Usability audit, Value engineering, Engineering analysis. The outcomes of product analysis will provide/identify the gaps for improvement, concepts generation for the improved product.
	How to select the concepts generated during designing phase?	Developed a framework for selecting an innovative concept during the design phase.

3	Can we develop a framework for achieving innovation during product design phase?	Developed a framework for selecting an innovative concept during the design phase.
	How such framework will compare relative innovation index amongst the given set of products of same family?	Using Linkography, a graph theory method - we developed a scale to measure relative innovation index of the products. Gaps/areas for further improvement in the products. Testing and validation: (through the case study) Testing and validation of the proposed framework by MSMEs

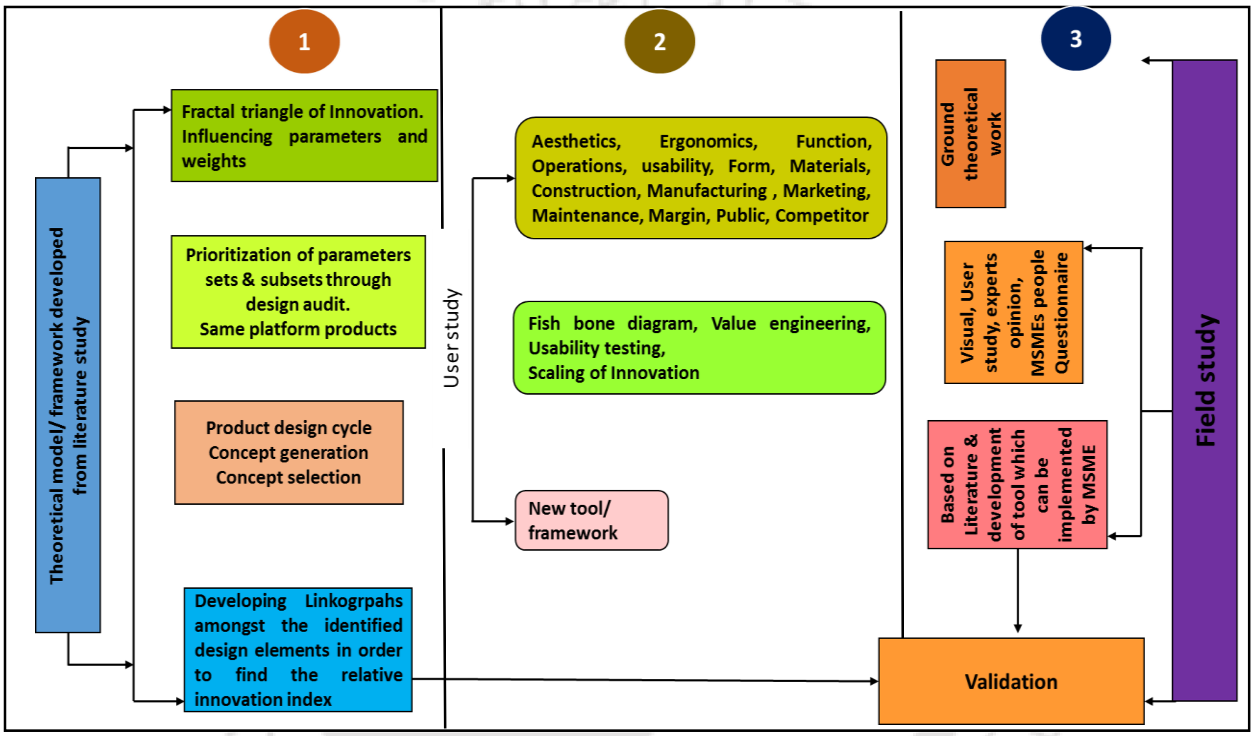


Figure 3.1: Stage wise research design plan

3.4 Description of 'Stages' of the research carried out

The entire study (Table 3.1, Fig. 3.1) was carried out in three phases as described below.

Stage 1: Emphasized on exploring various design elements which play vital role in achieving innovation during the product design stage. These variables are identified based on available literature in product design. Starting from Design Space theory lead us to identify the sub elements which ensure innovation in product design.

Stage 2: Its focus was to understand current practices, models and methods used by both designers and MSMEs. Suitability of available innovation models for Indian context for new product development was explored. An initial pilot study was carried out on two existing products manufactured by MSMEs. This pilot study involved application of several design techniques mentioned in literature with the hypothesis that if such methods/tools are found suitable, they could be used to build a new frame work specifically for the use of MSMEs. Some tools and methods used were Fishbone diagram, Usability audit, Value engineering, Engineering analysis, concept generation for the improvements in the product and concept selection matrix. These 2 experiments lead us to understand the product in a better way and prioritizing the identified design elements by pairwise comparison method. This study also helped in identifying the design elements. From this initial pilot study experiment the 'concept selection matrix' during designing phase emerged based on prioritization of design elements. Stage 2 provided us the initial glimpse of the Innovation frame work that was developed and validated at a later stage.

Stage 3: In this phase, the aim was to develop a framework for innovation. By experimentation, the framework for measuring and comparing the element of innovation for a given set of products was identified. The framework for innovation was validated in real time by encouraging the MSMEs to use it as an Innovation method and their responses were obtained. The MSMEs involved in the development and validation has been documented is listed below Table 3.2**.**

Together with the process, tools and framework in entirety – a framework is hoped to be evolved for the use of MEMEs.

Table 3.2: Attempts to give an overall view of the intent and approach adopted in the research.

Objectives	Detail task	Study area	Methods
Understanding the state of art of MSMEs products & influencing parameters	Detail study of MSMEs their practices level/ scale of innovation. PD cycle and parameters involved in it.	Indian MSMEs along with other countries, Innovation capabilities	Literature study, Journals, books, articles, and govt reports, various web sources
	Identification of parameters influencing innovation in products that are produced by MSMEs	Theoretical construct	Outcome of Literature review
	Basis for the case studies		**Qualitative approach using case study**
Identify the factors that influence the innovation and interrelations , weights	Case study :10 Products Design audit, pairwise comparisons	Understanding of products parameter prioritization and their weights	FBD, VE, EA, usability Methods adopted for Design Audit
	Similar family of products:5	Innovation scale development for these products	Questionnaire, user study, observations
	New method/frame work for MSMEs which can add value in terms of innovation Linkography in PD	Quality tools useful to MSMEs	Developing a tool which is easy to use as a morphology
Prioritize weights development of Linkography and measuring the innovativeness in the given set of products	Innovation influencing parameters are prioritized and weights are assigned based on the design audit of products Develop the linkogrpahs in relation with the design elements to find the relative innovativeness in terms of LI, CM	Identified Products Umbrella, Jar opener, Tablet+Laptop, Envelope maker, Iron, Garment Steamer, Blender	Field study : 1.Get validated the Design audit and prioritization and linkogrpahs from the experts 2.Apply our framework for identified MSMEs and check/ validate the methodology by showing improvement and get the feedback

For developing a frame work, inputs are required from the MSMEs. Hence the type of MSMEs type of products, practices etc. are discussed in the section 3.5 as follows.

3.5 Mapping of the needs of MSME with product design cycle

The methodology followed in field study to understand the practices and needs of MSMEs in order to map their responses with product design cycle is as shown in Fig. 3.2. It will help in understanding their methods and possible improvements one can bring about by developing a frame work.

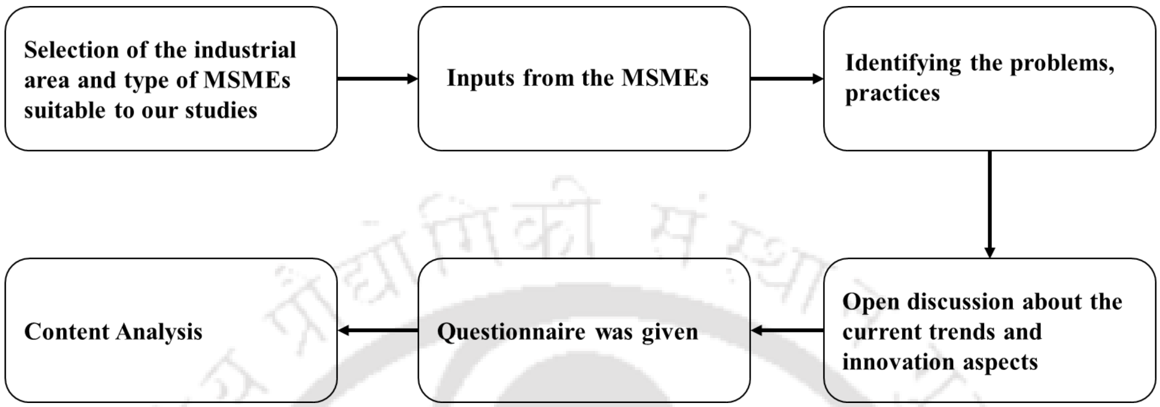


Figure 3.2: Process flow for field study and initial data collection

Industrial areas in and around Guwahati city were identified. Twenty-five MSMEs were approached out of which only ten MSMEs permitted us to give their time and feedback. Hence these ten MSME responses through a questionnaire, and ratings for the products (for experiment) by templates **(Appendix B)** were noted and recorded. The Table 3.3 lists out the MSMEs and their products, surveyed during the research study. The survey yielded the current status of affairs and preparedness regarding the new product development that is present in MSMEs.

Table 3.3: List of MSMEs involved in survey and their products

Ammingaon Industrial estate **Address:** Export Promotion Industrial Park - EPIP Amingaon Hajo Barpeta Road, Amingaon, Guwahati, Assam 781031	
Name of the MSME	**Products**
Policon	Plastic chairs, tables, Blow and roto molded water tanks, stools manufacturer
Supreme	Plastic chair, table, stools and HDP container manufacturer
Ahura Mazada	Metal fabricators, metal cupboards.
Adarsh	Commercial pet bottles, jugs, and other plastic utensils manufacturer and Openers (metal, stylish, fancy) other small household items.
Jayshree Umbrella Mfg. Co.Pvt. Ltd	Umbrella manufacturer (local brand only in season).
Brass artefacts	Hajo, traditional horai
Bamunimaidam Industrial Estate **Address:** Industrial Estate Bamunimaidan Guwahati, Assam781021.	
Thakaria Poly mech industries	HDP container manufacturer all shapes, Polythene tube/Roll plastic bags etc.
Prag electrical	Metal fabricators, Transformers electric

Mech tecknik	Metal fabricators, Gas stove manufacturer(Local)
Rika Engineering	Metal fabricators, Gates(stylish), manufacturer
L P Automotives	Agriculture equipment manufacturer
Raunaque communication	Electronic item manufacturer

A questionnaire **(Appendix A)** was given to ten MSME personnel. The MSME types considered in the study were: Traditional craft making industry (artifacts, metal, bamboo), Food processing equipment manufacturers, Household item manufacturers (Plastic covers, bottles, utensils, chairs, tables, stoves, etc.), Metal fabricators (gas stove, frames, structural designs, etc.).
The ten responding MSMEs are listed in above Table 3.3 along with their products and location. All the feedback was recorded and analyzed along with discussions regarding their practices. It has been analyzed by the content analysis method, as the questionnaire was descriptive followed by a formal interview.

3.5.1 Contents analysis of questionnaire data collected from 10 MSMEs

Content analysis is a method in which responses are grouped based on the identified keywords i.e. categorization of the responses and codes are extracted. We take each question one at a time and evaluate. Codes were identified for respondents and grouping was done. This is discussed in detail in the following section.
Q.1 Can you describe how you design the products?

Respondents answers for which key words were extracted and is shown below and same is followed for all the questions

-Generations -Adopting new things -Do not design entirely new product -Following new trends	-Own designs -Customer demands -Engineering teams -Skilled labors, Machines	-Experienced in this field -Understanding of problem -Experienced Engineers, labor, staff etc.	-Requirement list -Our team do design -Material, BOM, Cost -Discuss with customers	-Customer requirements -Color, volume, Shape, features -We manufacture
-Fix designs -Customer designs -Draw specifications	-Customer needs -What others have done?	-Customer designs -Experienced teams (R&D, Engg., Marketing) -Discuss with clients & in-house	-Experienced teams -Market trends -Feedbacks -Product design cycle -Prototype -Mass production	-We do not design -We buy designs

Q.1 Can you describe how you design the products?

Categorization of Q1, Key words	**Codes extracted using Content analysis technique**
A. Generations, Own designs, Experienced in this field.	Experience
B. Customer needs/demands/designs/specifications/requirements list, others have done, following trends, in-house discussion, fixed designs, adopting new designs, market trends, feedbacks.	Customer requirements, copy of designs
C. Engineering team, skilled workforce, R&D, experienced engineers, marketing, transportation.	Departments in MSME organization structure

D. Discuss with clients, customers, prototypes, production, manufacture.	Production/manufacture
E. Material, cost, volume, dimensions, BOM, style, weight, designs.	Drafting the designs/ inventory/production requirements
F. Do not design, outsource design	Buy designs/copy designs

Q 2. Do you follow any procedure for the development of products in your organization, if so what is the practice?

-Gather all the parts (plastic, metal) -Sub assembly, assembly -Packing, testing -Manually	-Study requirements -Develop plans -Inventory -Production -Procure small items	-Identify the problem -Check for a solution -Design drawings, material, safety, cost etc. Manufacture	-Different teams -Discuss with all teams -Manufacture	-Standard procedure -Requirements -Check, plan -Manufacture
-Buy designs, molds -plan assembly lines -manufacture	-Normal product design cycle -Company strategy	-No fixed procedures -On orders -Planning	-Observing others product - Product design cycle -No QFD, DSM,VE	-Organization structure -Company policies -All sections

Q 2. Do you follow any procedure for the development of products in your organization, if so what is the practice?

Categorization of Q2, Key words	**Codes extracted using Content analysis technique**
A. Gather all the parts, inventory, manufacture, buy designs, procure small items.	Procurement/manufacturing
B. Sub-assembly, assembly, production, plan assembly lines, planning, checking, manual assembly.	Assembly/planning
C. Study requirement, normal product design cycle, identify the problem, develop plans, check for a solution, discuss with teams, finalize design, standard procedure, requirements, product design cycle, discussion with all teams/sections.	Product design cycle Design phase
D. Packing, testing.	Quality
E. Design drawings, material, cost, on-orders, observe others product.	BOM
F. Company policies, organization policies, company strategy.	Mission/Vision, Organization structure

Q 3. How do you get Ideas for designing products?

-Standard designs -New style adoption	-No new product development -Different variations	-Observing -Drawbacks of others -Discussions	-Not generated -Add extra features -experience -Alternate ideas to the customers	-Observing others -Customer discussion -Old design modified
-Owner gets	-Other product	-Given by clients -Internet	-From surveys -user feedbacks	nil

-Buy the ideas and designs -Competitors product ideas		-Others product	-Product search in internet -Own designs -Discussion	

Q 3. How do you get Ideas for designing products?

Categorization of Q3, Key words	Codes extracted using Content analysis technique
A. Standard designs, observing, observing others, owner gets, given by clients, new styles adopting, different variations, drawbacks of others, add extra features, over the experience, customer discussion and teams, old design modified, buy the ideas and designs, competitors product ideas, others product, from surveys, user feedbacks, product search in internet, own designs	Idea generations
B. No new product development, ideas not generated, buy the ideas and designs from associates	Non generation of ideas

Q 4. Who decides on the design features of your product and what is the basis on which you decide?

-We only decide -Not customer based	-Our engineers -Experienced	-Our engineering team -Experience	-Customers -Experienced engineers	-Our team discussion and suggestion on material, cost, size, color etc.
-We do not -Market trend -Buy the final designs	-We decide -client decide both	-Customers -sometimes designed in house	-Engineers -R&D people -Competitors product	- Customers -Our engineers

Q 4. Who decides on the design features of your product and what is the basis on which you decide?

Categorization of Q4, Key words	Codes extracted using Content analysis technique
A. We only decide, our engineering team, experienced, our team discussion, our engineers, R & D	In-house (Deciding design features)
B. Customers, market trend, buy the design, observing competitor's product	External (Deciding design features)

Q 5. From the series of product, you manufacture, can you identify few innovative features that you think you are providing, that your competitor is not

-Size -Various colors -Different material -Low cost	-Latest designs -Good finishing	-Competitors product -Less cost -Lighter, durable, grip, ease of use, less maintenance	-Good quality -Colors -Good finishing	Same as competitor
-Light weight -Stylish, colors -Cost -Strong and durable	-No such difference	-Light weight -Colors -Good finishing -Different material	-Good quality -Cost -Simple assemblies	-High quality -Size and colors -Cost less -Strength and durability

Q 5. From the series of product, you manufacture, can you identify few innovative features that you think you are providing, that your competitor is not

Categorization of Q5, Key words	Codes extracted using Content analysis technique
A. Size, variety of colors, different material, less cost, light weight, good finishing, durable, strong, ease of use, less maintenance, good quality, simple assembly and disassembly	Innovative features
B. Same as competitors product, No such difference, we do not design	Non-innovative

Q 6. In general, what is your understanding and view on the word innovation?

-New product development	-Good product at lower cost	Creating products with new materials and designs	-More features -Lower cost -Light weight -More durable	-Broad term -Context -Creating best products and processes
-Newly created -Advance function	-Adding features -Reducing cost, process time -Improving process, machines	-Creating new product -More features -Less cost -Good looking	-New product development -More functions	-Changing the material, process -Increase the production

Q 6. In general, what is your understanding and view on the word innovation?

Categorization of Q6, Key words	Codes extracted using Content analysis technique
A. New product development, new materials, low cost, more features, better looking, improving process time, machines, production rate, advanced functions, context specific	Innovation is

Q 7. Any other comments and suggestions you wish to give

-Include technical parameters	Nil	-Good work	-Good work -Make software	No
-Good -Comparing two products -Improvement areas -Simple	-Quick insights of 2 products -Focus on improving machines -Here it is difficult to seed such practices	-It is lengthy -Good effort	No	Good -make software

Q 7. Any other comments and suggestions you wish to give

Categorization of Q7, Key words	Codes extracted using Content analysis technique
A. Good work, nil, no, good for comparing two products, improving areas, simple, good effort, quick insights of two products	Comments
B. Include technical parameters, make software, its lengthy, can focus on improving machines	Suggestions

After the study of codes of all seven questions from 10 MSMEs, responses are compiled and are tabulated in table 3.4 as shown below.

Table 3.4: Codes Identified as a results of data collected for 10 MSMEs

1. Experience	**7.**Procurement/manufacturing	**12.** Idea generations
2. Customer requirements, copy of designs	**8.** Assembly/planning	**12.** Non generation of ideas
3. Departments in MSME organization structure	Product design cycle design phase	**13.** In-house (Deciding design features)
4. Production/manufacture	**9.** Quality	**13**. External (Deciding design features)
5. Drafting the designs/ inventory/production requirements	**10.** BOM	**14.** Innovative features
6. Buy designs/copy designs	**11.** Mission/vision, Organization structure	**14**. Non innovative
15. Innovation is		
Comments		
Suggestions		

For the extracted codes from the questionnaire, the frequency of the occurrence by each of ten MSME respondents is shown in Table 3.5 (Some people gave multiple answers hence the number of responses are more than ten).

Table 3.5: Codes and number of responses

Codes	**No of responses**
1. Experience	3
2. Customer requirements, copy of designs	12
3. Departments in MSME/organization structure	6
4. Production/manufacture	4
5. Drafting the designs/inventory/production requirements	8
6. Buy designs/copy designs	2
7. Procurement/manufacturing	6
8. Assembly/planning	7
9. Quality	2
10. BOM	4
11. Mission/vision, organization structure	3
12. Idea generations	19
12. Non-generation of ideas	3
13. In-house (Deciding design features)	7
13. External (Deciding design features)	4

14. Innovative features	14
14. Non-innovative	2
15. Innovation is	18

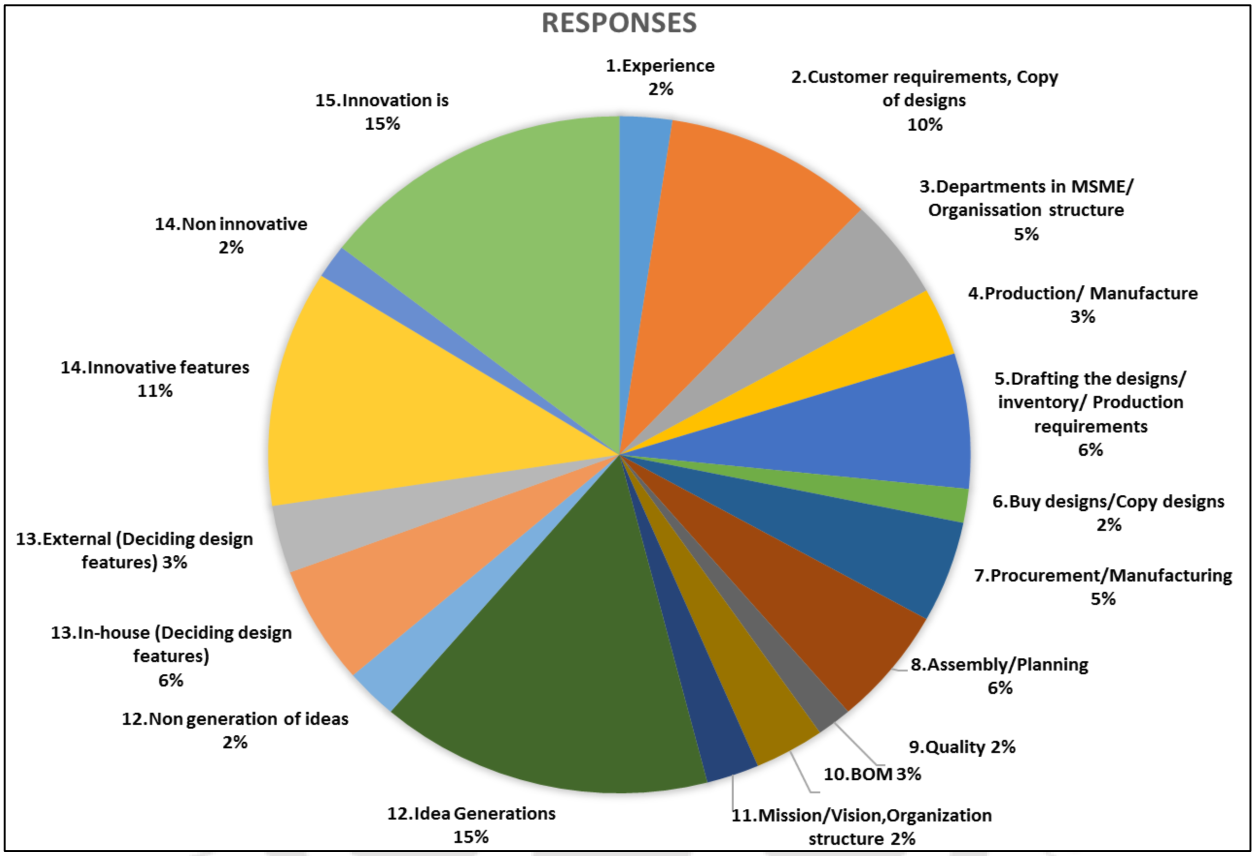
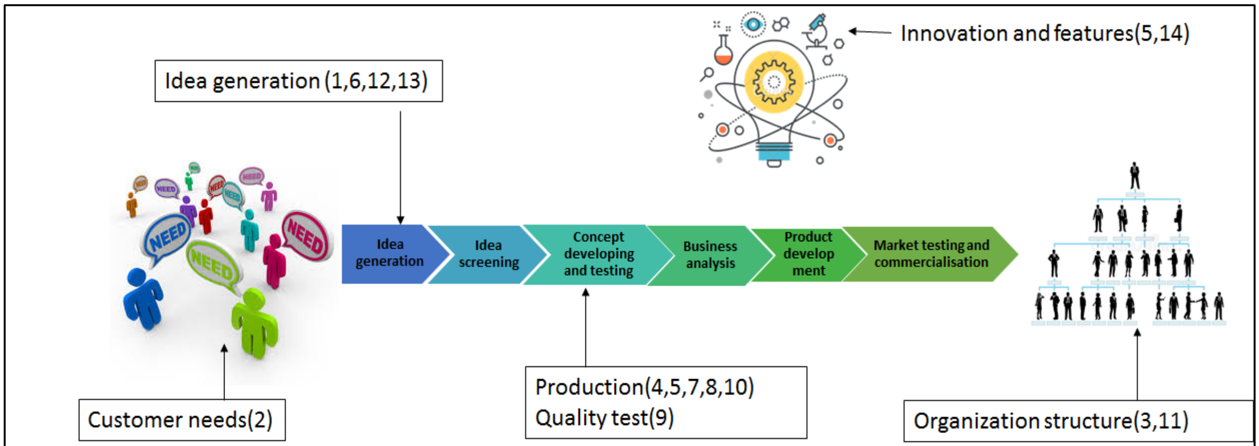


Figure 3.3: Results of content analysis



Codes	Responses
1.Experience	3
2.Customer requirements, Copy of designs	12
3.Departments in MSME/ Organization structure	6
4.Production/ Manufacture	4
5.Drafting the designs/ inventory/ Production requirements	8
6.Buy designs/Copy designs	2
7.Procurement/Manufacturing	6
8.Assembly/Planning	7

9.Quality	2
10.BOM	4
11.Mission/Vision, Organization structure	3
12.Idea Generations	19
12.Non generation of ideas	3
13.In-house (Deciding design features)	7
13.External (Deciding design features)	4
14.Innovative features	14
14.Non innovative	2
15.Innovation is	18

Figure 3.4: Content analysis mapped with product design cycle

3.5.2 Inferences from the mapping of content analysis and product design cycle

The total respondents were ten, a formal questionnaire has been administered and responses were recorded as well as noted. To encode it, we carried out content analysis for the individual questions for all the respondents.

Organization structure is also important as finer ideas come from the discussion with all the teams. Six companies answered 'yes' for the same. Four respondents said that the design products are production or manufacturing related. 8 respondents believe that material, cost, volume, color etc. are product design, but they are the properties of the product. Two responded as buying the design or outsource the design (similar to copy paste legally). Overall, on close inspection, the respondents were focused more on their experience, customer requirements, inter departments, manufacturing and sometimes outsourcing the design and their practices (some gave multiple answers so it is more than ten).

When the question asked was 'Do you follow any procedure for the development of products in your organization, if so what practice? Six responses answer were towards procurement/manufacturing processes, seven have shown keen interest in the assembly and planning, two were quality test and four were BOM (Bill of Material), three were following their company strategy. All were aware of the product design cycle and some were following it in one or other way. But when observed closely it can be seen that partly they are indeed following the product design cycle but they follow their own methods for designing and manufacturing of the product which is experience based rather than proven method based.

When the posed question is ‘How do you get Ideas for designing products?’ Around nineteen (multiple answers) responses were pointing at standard designs, observing, observing others, owner, given by clients, new styles, adopting, different variations, drawbacks of others, add extra features, experience and many more which are idea generation as per them. Three responses were no new product development and ideas are not generated, and they buy the ideas and designs from associates.

For the question ‘Who decides the design features in your product and basis of the decision?’ the design features are decided in house i.e. employees decide, engineering team, based on experience, team discussion, R&D. Seven respondents agreed for this and four responses were externally outsourcing for designs which includes customers, market trend, buy the design, observing competitor’s product.

‘From the series of product manufactured by you, can you identify a few innovative features that you think you are providing compared to your competitor? Fourteen responses were size, variety of colors, different material, less cost, light weight, good finishing, durable, strong, ease of use, less maintenance, good quality, simple assembly and disassembly as innovative features of the product. Two responses state that they were same as competitor’s product.

‘In general, what is your understanding and view on the word innovation?’ eighteen responses were as follows new product development, new materials, low cost, more features, better looking, improving process time, machines, production rate, advanced functions and context specific. Again, it is their understanding of innovation and how it has to be practiced.

Content analysis overview is shown in following Fig. 3.3, which gives the percentage wise responses in pie charts.

From section 2.11, Fig. 2.15 chapter 2, product design cycle is mapped with results of content analysis as shown in Fig. 3.4. The observation out comes are: Idea generation as experience, buying design/copy designs and in-house design. Which shows that there is no practice of core idea generation in MSMEs. Even customer needs are decided based on the copying of others designs. Lack of concept development and testing phase, production/manufacturing, drafting the design, inventory, bill of materials and the organization structure was not proper. Innovation and creativity, according to their thinking is adding features, color and drafting. By observing all these coded responses mapped with product design cycle, there is need of a simple method to achieve innovation without any external aid or help. Better understanding of the competitor’s product and value addition in the products is lacking. Hence this research is focused on developing a simple and effective method for innovation.

3.6 Design of Experiment involving Design Audit

The Fig. 3.5 below explains detailed schema, of conducting the experiments. This includes choosing the product, design auditing and generating Linkographs which are discussed in detail in later chapter 4 and 5.

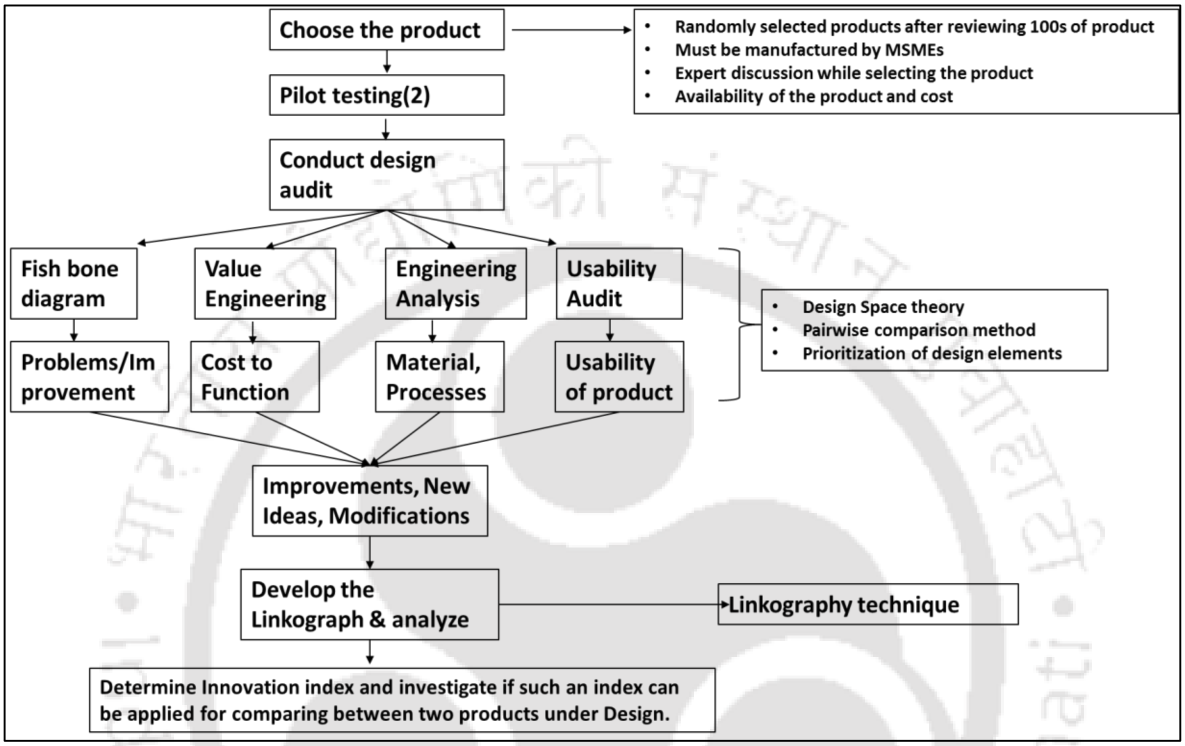


Figure 3.5: Shows the overall experimental analysis planned for the research

3.6.1 Experimental procedure

The methodology employed in conducting pilot study and main experiments is outlined in Fig. 3.6. For analyzing products, we adopted some of the available tools and methods (mentioned in chapter 2).

The following Fig. 3.6 depicts in detail, the steps involved in product analysis/audit for the selected products. These steps have been also retained in carrying out analysis in the major experiments as well. The product analysis steps are as shown in Fig. 3.7, in which external observation and internal observation, disassembling, analysis, compiling, generation/selection of ideas are shown. Details regarding the surveys conducted are discussed in above section.

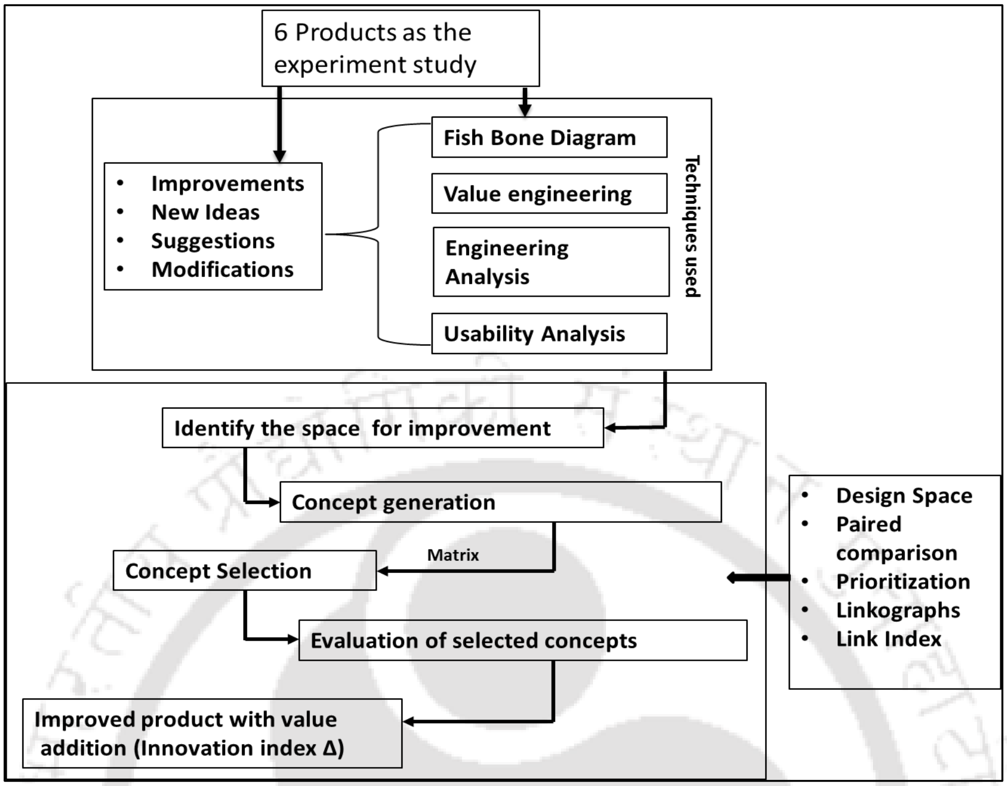


Figure 3.6: Plan for the design audit for pilot study and main experiment

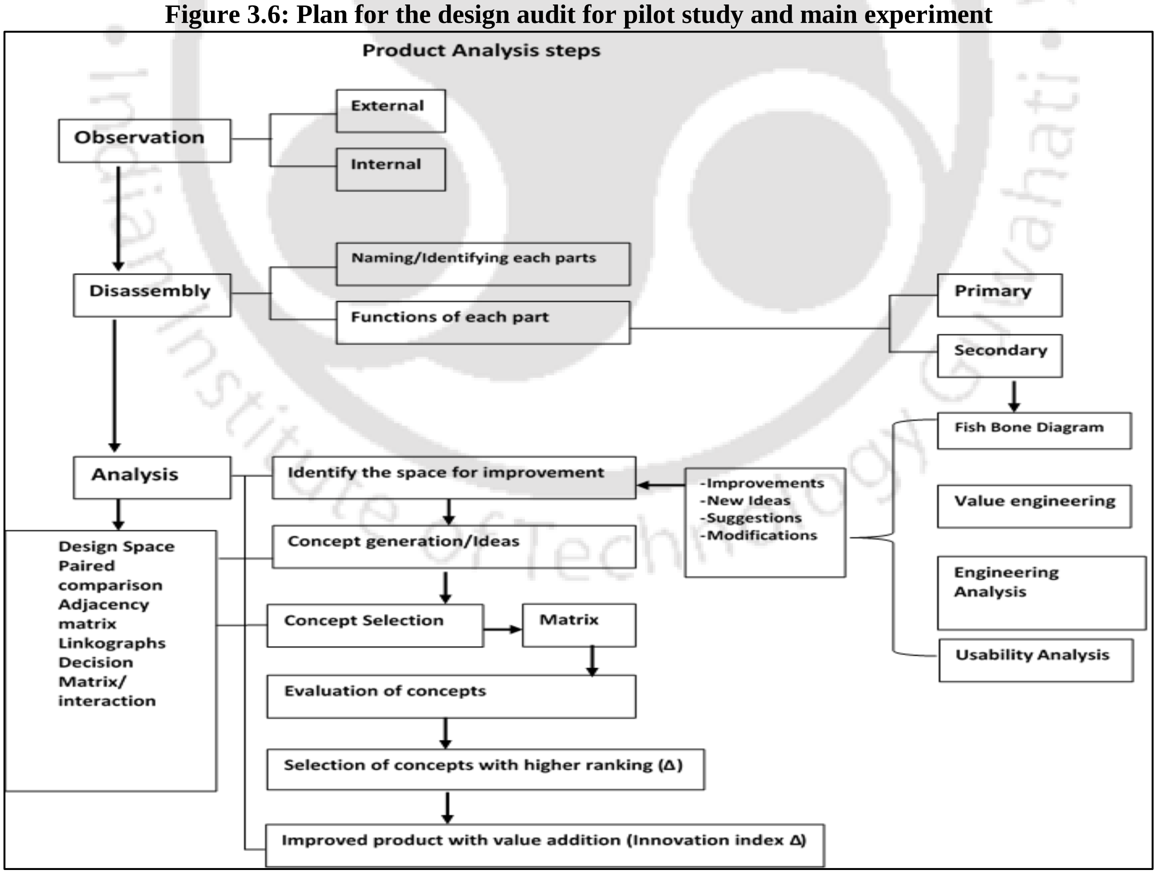


Figure 3.7: Steps for product analysis/ Product analysis an overview

3.6.2 Design Audit of products manufactured by MSMEs

Design audit of a product is done to take stock of the present design and find deficiencies which could be improved, or which could be pointers to spot within the product wherein value addition could be done. A product design audit process will help improve its design and functionality according to latest market trends and end-user needs. The term is gaining currency as a method of checking status of a Design output's performance by Design management business firms [nibusinessinfo.co.uk], [symphony-solutions.eu] and is also used in class room training sessions [Yammiyavar, 2004]. Design audit in this thesis is done by using analysis tools and methods that originate in Value Engineering and Operation Management. Value engineering is a systematic method to improve the "value" of products and services by using an examination of the part's function with its cost. Value, as defined, is the ratio of function to cost. In this thesis Design Audit has been adopted as the primary approach for analysis of existing products in combination with Value Engineering.
Review of literature leads us to the inference that innovation is a qualitative term and difficult to quantify. Variations in customers and manufacturers perspective related to innovation adds on to the difficulty. Hence it is posited that building a framework for practicing and indexing innovation, especially for MSMEs would help them in identifying and quantifying variables in innovation. Design audits are rarely performed in the MSME's as the process of designing the product is either adopted from the available designs without defining the time frame of its utilitarian benefit or importance to the customer. Market aggregation is a most popular technique adopted to suit the design needs of the larger market. The selection of products samples in our analysis was done on the basis of them being manufactured by MSMEs and they are used for major experiments based on visual investigation and discussions with experts.

3.6.3 Visual investigation of the products and archetype products

The selection of products for the experiments was done after examining a list of hundred randomly chosen possible listing of household or everyday use artifacts. Other factors that were considered to narrow down the selection to seven type of products, are mentioned below:

1. The products should have been manufactured by MSMEs.
2. The product should be novel in the sense that they should have good features, of low cost with multiple use functions. The design should be an improved version of an existing product of a previous generation
3. The product selected will preferably fall under PPF zone 3 [Yammiyavar, 2004].
4. The product should belong to a family of products with more value addition in it as decided between three product designers by informal discussions.
5. Archetype products were given more preference than me to type of products.

Considering all the above points for the selection of samples for analysis research experiments, we selected seven cases (Table 3.6 for product photographs) as follows:

Case 1. Multipurpose openers- 3 numbers labeled as of different openers as Opener A, Opener B and Opener C to enable auditing their innovative content by comparison.

Case 2. Rain Protection devices such as Umbrellas - 3 numbers; and rain coat. They are labeled as U1, U2, U3, and R1. Umbrellas and raincoats are not archetypes, but in our research we have considered function of both products as common utility factor.

Case 3. Envelope Making setup -2 types (One is Chinese made with higher cost, the other one was developed in the lab as no similar Indian product was available. They are labeled as A & B.

Case 4. Computing devices - One tablet with cover tablet and one Tablet without cover.

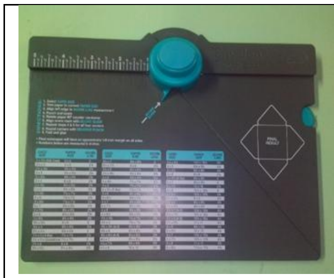
Case 5. Blenders - Electric and mechanical type (Only Linkographs have been developed)

Case 6. Garment Steamer compact and big (Only Linkographs have been developed)

Case 7. Iron box normal and inbuilt steamer (Only Linkographs have been developed.)

Table 3.6: Selected products for the analysis/audit

 Opener A	 Opener B	 Opener C	 Earwax remover  Solar powered auto vent cooler
 Umbrella U1	 Umbrella U2	 Umbrella U3	 Raincoat R1

<table>
<tr>
<td>
Envelope Maker A
Chinese made</td>
<td>
Envelope Maker B
Lab developed</td>
<td>
Computing devices A and B</td>
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<tr>
<td>
Blender A</td>
<td>
Blender B</td>
<td> Iron A
 Iron B</td>
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<tr>
<td colspan="3">
Garment Steamer big A and compact B</td>
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</table>

The above products have been subjected to Design audit, which are discussed in the subsequent chapters.

Summary of chapter 3: This chapter discussed the research methodology used to carry out the research experiments. The initial studies, interviews, discussion are included. Details of experiment design, surveys conducted, along with pilot and main experimental procedure. Pilot testing and main experiments conducted along with linkograph generation are presented in next chapters.

Chapter 4

4.Innovation Framework/Model - proposal

Abstract: Based on the insights from the literature discussed in earlier chapter 2 and following methodology in Chapter 3, a conceptual frame work - to develop a new innovation model has been presented in Chapter 4. The basis on which the proposed Innovation Frame work has been conceived is described. Using two products as experimental samples, pilot testing of the proposed frame work has been done to ascertain its theoretical as well as structural construction. In this chapter only the basis of frame work, its development and its validation by pilot testing has been dealt with. The developed frame work has been used to conduct the larger experiment which is reported in the next chapter.

4.1 Introduction

The type of research in this thesis comes under 'Exploratory'. Posits have been made, alternative methods and processes have been evaluated and deployed. The experimental product analysis has been done to validate the approach which eventually will lead to our proposed innovation framework for MSMEs. The objectives, research questions and stages were discussed in chapter 3. The proposed frame work is intended as a model using which MSMEs can systematically ensure incorporation of innovation. Any such model needs to have a series of tasks executed to achieve a higher degree of value addition especially during the product's conceptualization stage itself.

4.2 Proposed frame work for innovation in product design

The Measurement and evaluation of Uniqueness or Novelty in a product design, that makes the usage easy for the customer and increases the utilitarian value is a difficult task to incorporate. Because designing the product requires a number of cyclic iterations. There is a possibility of losing track during one of the iterations or dropping of variables. Hence establishing a matrix like metric that measures the innovativeness or uniqueness in product design and features that add value from the user's perspective is proposed below.

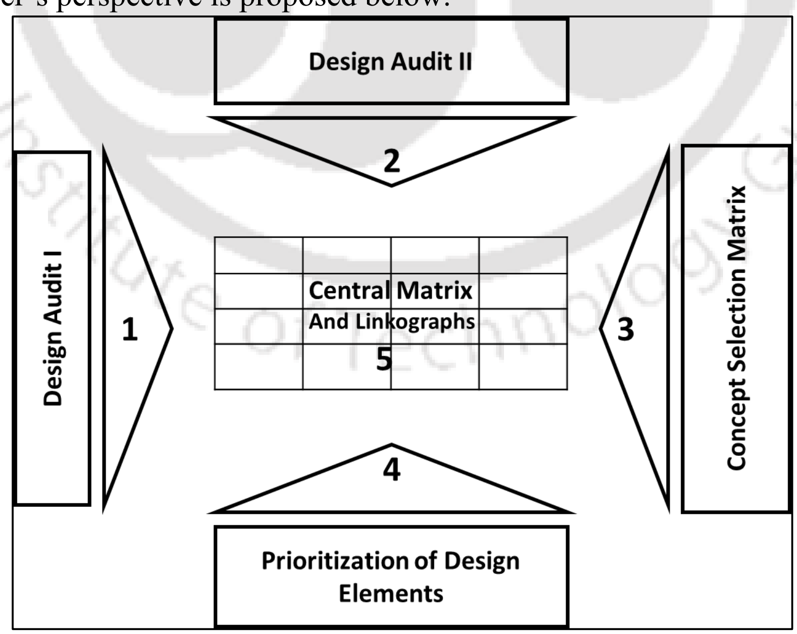


Figure 4.1: Proposed framework of innovation as posited

Fig. 4.1 is the proposed hypothetical conceptual framework for measuring as well as implementing innovation. The proposed framework can also be used in reverse as shown in the Fig. 4.2. The advantage of reversing can be used to analyze and measure the innovation index of the existing product and then go backwards in the design as innovation. When the framework is reversed, it is possible to calculate and find the innovation index of the new product. Hence the proposed framework has a dual leverage of reversing. The Fig. 4.2 is the combined framework, in which dotted lines indicate when the framework is reversed. It can be utilized to redesign an existing product or a new product design.

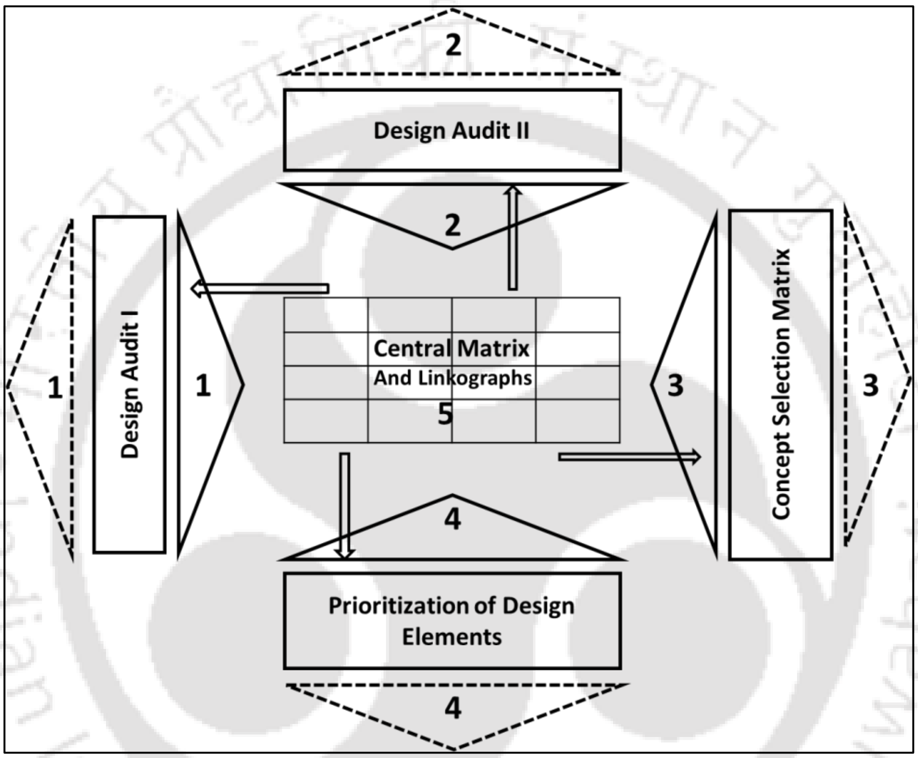


Figure 4.2: Proposed framework combined as one

The proposed framework has been conceptualized with four inputs resulting from five analysis tools/processes which are already available in state of the art literature and design practices. Referring to Fig. 4.1, each of the five components numbered 1 to 5 are described below:

The Design audit, results in pinpointing specific areas/features/parts of improvements. It is divided in two parts (I and II) as:

1. **Design Audit Results I**: Consists of Value Engineering, Engineering Analysis, Fishbone diagram. These methods were selected based on the literature survey followed by heuristic analysis carried and discussed in the following sections.

2. Design Audit II results: Concerns attributes like User Centered Design-Usability Engineering includes Usability testing based on 5 E principles. It has been adopted from ISO standards, from User Centered Design and it comes from Design morphology.

3. Concept selection matrix is intended for selecting the concepts generated during the design phase based on rating the value addition by design. This has been developed and discussed as 'Development of Concept selection matrix and computations' in the following sections.

4. Prioritization of the design elements helps designers and MSMEs to prioritize the design elements during the designing phase. Based on the pairwise comparison method, it is a kind of divide-and-conquer problem-solving method. It allows one to determine the relative order (ranking) of a group of items. This is often used as part of a process of assigning weights to criteria in design concept development. The parameters influencing innovation during the product design are identified and is the basis for the development of novel fractal triangle of innovation discussed in following sections.

5. Linkographs (core of the framework) is the central line of the framework. Based on the graph theory a technique termed linkography is utilized in developing the proposed framework, which gives the differential innovation index or relative innovation index.

Given a set of archetype of products – Des 1, Des 2, Des 3 analysis or design audit is carried out for each product using the four tools sets. This results in the central matrix in Fig. 4.1 being populated. The central matrix gives a relative index for each of the Des 1, Des 2 and Des 3 products. Using this index, one can compare them to assess and help in identifying which of the products has more value addition and in which specific part/subassembly.

Tool set 1 Technical tools already available as Value Engineering, Engineering Analysis and Fishbone diagram.
Tool set 2 Human Centered Design-Usability Engineering emerged from ISO standards, User Centered Design, Design morphology.
Tool set 3 Assigning rankings by adopting the technique of 'Pairwise comparisons'.
Tool set 4 Concept selection matrix has been developed by the authors.
Tool set 5 is Graph theory based method 'Linkography' is employed to measure the innovation index.

For existing products, the tool-sets are readily usable by disassembling the products. In the case of a yet to be manufactured product, product technical drawings or mockups or prototypes are used to carry out the design audit. The output of the framework gives degree of innovation in comparison to other similar category products; provides a diagnosis tool to identify potential parts/features of the product wherein value addition maximizes the total innovation content of the product.

The proposed Innovation frame work/model can be used both as an 'Innovation Audit tool' as well as 'Design Innovation' tool. In both cases the matrix yields a qualitative index which is proposed as a measure of innovation in this thesis.

4.3 Basis of Development of the hypothesized framework and its components

Where all does the innovation reside in a product is an abstract knowledge question that is not evident. A product is often more than a sum of its parts. Summating the inferences from studied literature it can be said that innovation is more of a qualitative concept when attempts are made to described it. In engineering there exist quantitative properties that indicate discreet levels. However, in user centered design, since human factors are involved Innovation is a combination of quantitative plus qualitative dimensions. Quantifying innovation is therefore vague and a difficult task, as the perceptions and perspective of innovation change from individual consumer to an individual manufacturer. Changing market dynamics and volatility in consumption patterns of user in future is likely to increase the difficulty for Indian manufactures as no proper tools exists to quantify the concept of innovation. This was discussed in Chapter 2 under literature study. The perspective of understanding innovation by MSMEs and designers of product is different, is shown in Table 4.1.

Table 4.1: Understanding innovation by MSMEs and designers point of view

MSMEs point of view, innovation in products means	**Designer point of view, innovation in products means**
Reducing costs	Manufacturing processes
Optimizing design	Materials
Redesigning the product	Marketing strategies
New materials	Policies
New manufacturing techniques	**Product design**
New tools and techniques	User Centered Design
Process improvement	Designer thinking
Product Service systems	
Marketing and branding	

General perception about innovation in products is ‘creating something new’ - new in terms of material, function, utility and also novel looks or ‘Form’. Given a product, the general belief about innovation is that it resides in different spots or features /components/subassemblies in a product, but where and how much is elusive and often remains unanswered. Therefore, a design audit through reverse engineering of the product needs to be carried out.
Design Audit of products will lead to the following:

- Design audit is the function of reviewing or assessing existing product designs. It is also employed in evaluating a series of generated design concepts.
- Design audit is conducted to understand positive, negative aspects of a product of existing design. It does not give any solutions and improvements for the irregularities in the product. (Fish bone diagram)
- Design audit outcomes are useful to analyze and compare the competitor’s product (Value engineering/Value analysis, Engineering analysis)
- Design audits are also carried out to understand the level of organization in terms of productivity, value additions, strategies, quality of products and customer feedback.

- Better understanding of products and user perception (reverse engineering, usability audit).
- Possibilities (weak areas) of redesign and optimization.
- Make us understand the defects in the products that are manufactured by MSMEs.
- Problems in the current design and solutions or generating entirely new solution keeping functionality unaltered.
- It will allow us to add value to the products while designing.

While conducting design audit, we are also evaluating the tools and techniques for their effectiveness to aid MSMEs efforts for implementing Innovations.

Design audit in this thesis is done using analysis tools and methods that originate in value engineering and operations management. Value engineering is a systematic method to improve the "value" of products and services by using an examination of the part's function with its cost. Value, as defined, is the ratio of function to cost. In this thesis design audit method has been adopted as the main method for analysis of existing products as part of research experimentation in combination with value engineering. The proposed frame work with all its dimensions is as shown in Fig. 4.3.

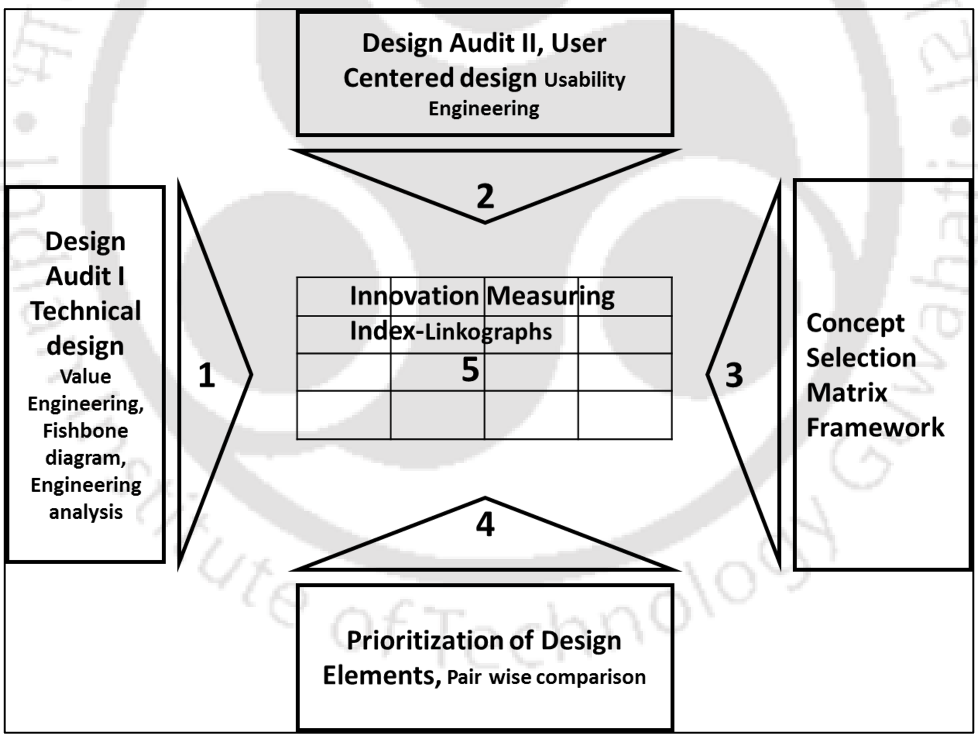


Figure 4.3: Proposed framework with all its dimensions

4.4 Experimental method adopted in conducting Pilot study

General perception about innovation in products is creating something new or new in terms of material, function, utility to name few, which does not occur regularly. From the literature we understand that high potential in achieving innovation is from usability and design point of view. The following Fig. 4.4 shows the perception of innovation in products.

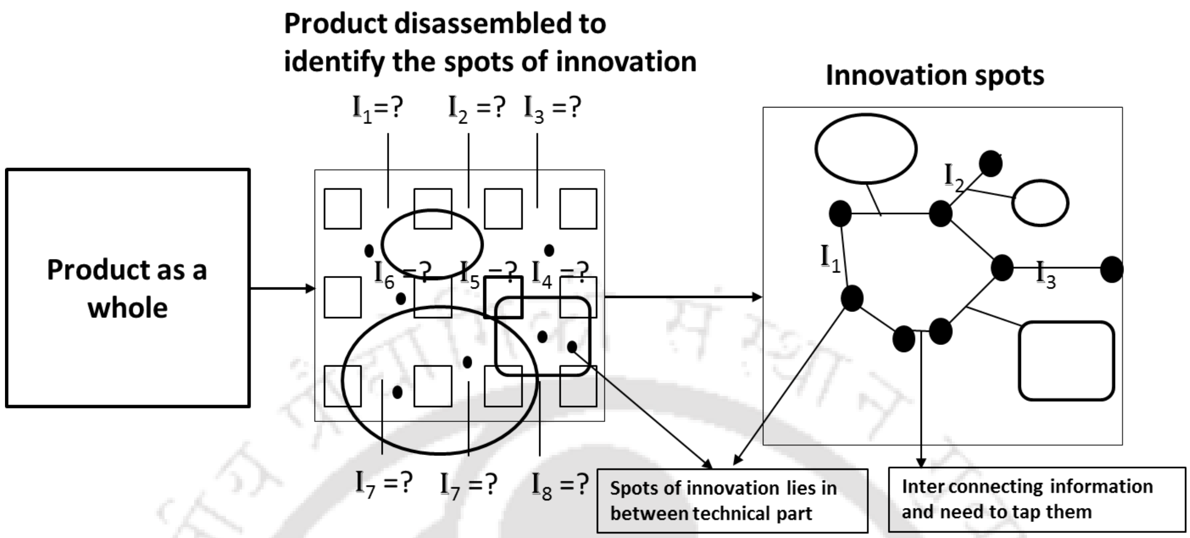


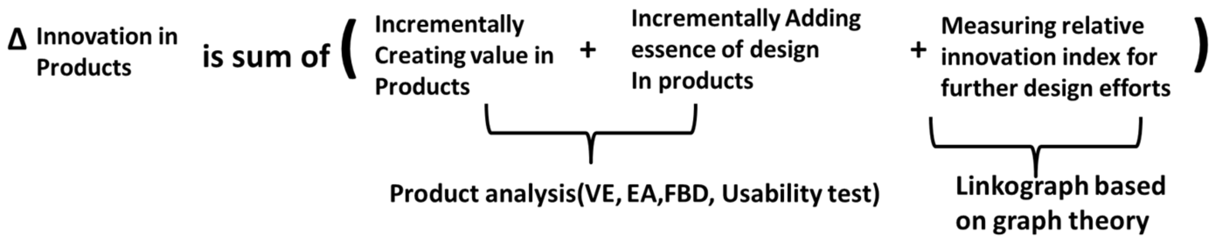
Figure 4.4: General perception of innovation in products

Innovation can reside in a product, physical parts of the product or in qualitative features. In the Fig. 4.4, Innovation = Σ (I_1 + I_{2+} I_{3+} I_{4+} I_{5+} I_{6+} I_{7+} $I_{8+....}$ I_n). However, innovation can also reside in aesthetics or visual quality or the ease with which a product can be operated by the human user. Innovation is therefore synergistic with a sum which may be greater than the sum of the parts.

Any framework that intends to be useful in innovation will need to cater to both – the qualitative as well as quantitative aspects. In the proposed framework quantitative aspects are planned to be addressed incorporating known tools and methods as used in value engineering through reverse engineering.

The qualitative aspects are intended to be addressed using Usability and User Centered design practices. These are not widely known and are in nascent stages of development in the discipline of product design. Both the types, namely qualitative and quantitative aspects are interlinked and need another type of analysis tool which belongs to system sciences. Graph Theory is proposed to be used as part of the proposed Innovation framework.

Innovation is incorporated in links, not only in the chunks as is the general perception. By links we mean those interconnected invisible nonphysical properties that define the interconnectedness of any system of composed parts in a product. These are often qualitative and therefore, we propose to adopt 'Linkograph' [Goldschmidt, 2014] technique to unfold the spots of innovation by micro steps analysis which has taken place during the designing phase.



…………. Equation 1

4.5 Development of Concept selection matrix and calculations for the product we made through case study

Evaluation of concepts (proposed framework for MSMEs), adoption of proposed metrics
From the literature studied two broad factors have been identified that could assist measurement of innovation. They are (i) Novelty (ii) User Centered specifications that become the criteria for design evaluation.

The proposed metric concepts discussed in this study were subjected to trial via three design cases involving development of simple products for use by mentally challenged users. Developing products for differently abled people is a user centered design criterion and it is a challenging task. Ease of operating by the differently abled people, along with the novelty of the solution was under trial in the cases taken up for evaluating the innovation component of the design. This study was used to find out if a matrix approach to design evaluation can be evolved. The experimental task was to construct an evaluation matrix and evaluate by ranking - the three products and the methodology undertaken by the three designers. The three case studies were observed while the designers were in the process of designing, prototyping and improving the designs. These three devices were meant to facilitate self-employment of the mentally challenged users to encourage them to lead an independent life. Products to be produced by them using the 'devices' (akin to jigs) under design by three designers - were (i) Handmade envelopes (ii) Paper bags making and (iii) Office files fabrications. These were chosen for trials due to their simplicity in terms of number of parts and the high content of Human Centered requirements to be considered while using them.

Before embarking on the design of device, field studies were done by the designers of the devices and involved other subjects and their supervisors. Observation and photo documentation suggest that the mentally challenged user subjects who were involved in making these envelopes were taking excess time and performed a number of steps to make an item. Another difficulty that was faced by them was inability to maintain dimensional standards and consistency resulting in large variations in quality and finish. Constant prodding to try and adhere to proper dimensions was a challenge for the user subjects. The user subjects employed traditional paper cutting methods using sharp knives and blades which needed supervision. Since they are differently abled, the chances of getting hurt was always present. The folding, gluing and packaging of these envelopes done by the user subjects were not perfect. There was a need of design intervention and innovation in this problem. Similarly, other products made by them such as paper bags and office files, also needed design intervention and improvement.

Three designers engaged themselves in creating interventions for three products, namely (i) envelopes (case 1) (ii) shopping bags (case 2) and (iii) office file folders (case 3). Designers used different design methods such as brainstorming [Besemer, 1998], SCAMPER, lean design thinking and other methods to resolve the problem. The aim was to evaluate the end resulting devices and rate their designs on innovation criteria. To select the most innovative and effective design amongst the proposed designs involve evaluating a series of interconnected outputs. A design matrix framework was developed on similar grounds to that proposed by Justel, et.al., [2007]. It was modified and adopted according to our problem as shown in Table 4.2.

A work carried out by [Garcia and Calantone, 2002] is referred for constructing Table 2.4, chapter 2 to obtain/assess the degree of newness. Apart from this, designers can contribute in assigning the degree of newness, based on their experience and knowledge of product context based on the listed discontinuities.

Out of many design methods, we can choose simple yet effective design method in order to get better solutions. Design method does not have any direct effect on evaluation of concepts. But a good design method for a better solution can be found out by conducting experiments and using concept selection matrix. This approach has been attempted here.

Table 4.2: Sheer Innovation ranking framework after modifying the one suggested by Justel et al., [2007]

			Conceptual designs	**Design 1**	**Design 2**	**Design 3**
			Degree of newness			
Sl. No.	**Design methods**	**Design criteria**	**Criterion weightage**			
1	**Brainstorming**	**Low Cost**				
2	**Lean thinking**	**Light Weight**				
3	**SCAMPER**					
4	**Group discussion**					
			Absolute Innovation prospect			
			Normalized Innovation Potential			
			Rank			

Selection of design criteria based on cost, weight, time, etc. as shown in above Table 4.2

1. Assessment of the degree of newness of conceptual designs the designers identify newness based on Table 2.4, chapter 2.
2. Select appropriate design method.
3. The design criteria are placed in the 2nd column and criteria weights are given according to their significance.

4. The correlation between design criteria and conceptual designs is determined in the matrix. With this, we can evaluate the effectiveness of each conceptual design that meets a given design criterion. (design criteria strong=9; medium=3; weak=1)

5. The Sheer Innovation Prospect of all designs is calculated by using equation 1. It is then normalized to attributing a value of 100 to the highest-scoring design and corresponding scores are calculated for all designs, and the highest scorer will be more innovative than the other designs.

$$\text{Sheer innovation Prospect} = \left[(\Sigma \text{ Design criteria- Concept relationship}) \times \text{ Criterion Weights}\right] \times \text{ Degree of newness}$$

… Equation 2

We explored the basis for concept selection matrix based on a case study as explained above.

Once the Table 4.2 is generated with all the data obtained by experimentation, one can use the above equation 2 to compare and generate overall innovation rankings for the conceptual designs. The concept with the highest rank should be selected for further development. Based on pilot studies, we are formulating further variables and study plan for main experiments to build our proposed model of innovation as posit.

4.6 Selection of Design audit tools from available tools for incorporating them into the proposed model, Qualitative aspects:

While there are existing tools in engineering such as value engineering, reverse engineering for measuring the phenomena of technical innovation content or value addition by materials, processes and technology. The qualitative aspects of products such as aesthetics, ergonomics, usability are often left out by the MSMEs even after they are aware in general of their role in product quality.

In the proposed model the qualitative aspects are mapped to be quantified using Usability Engineering principles in conjugation with UCD approach. This has been tried out under the theory of 'Design Space' of a product by designers. This term - Design Space of a product intended to mean Conceptual space of a Product, has been adopted in this report based on its appearance in published literature [Yammiyavar, 2004; Yammiyavar, 2005] to describe a diagnostic critical micro-examination of a product's design as seen from the user's point of view. This has already been discussed in chapter 2 under section 2.9. The Fig. 2.13 in section 2.9 partially explains the concept of design space which is reproduced in Fig. 4.5.

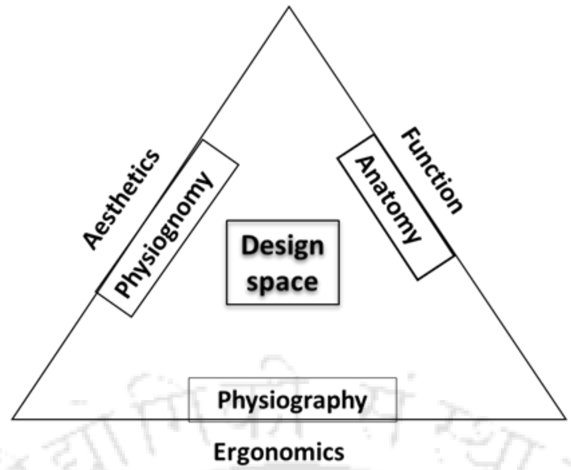


Figure 4.5 a: Design Space adopted and redrawn from Yammiyavar. P [2004]

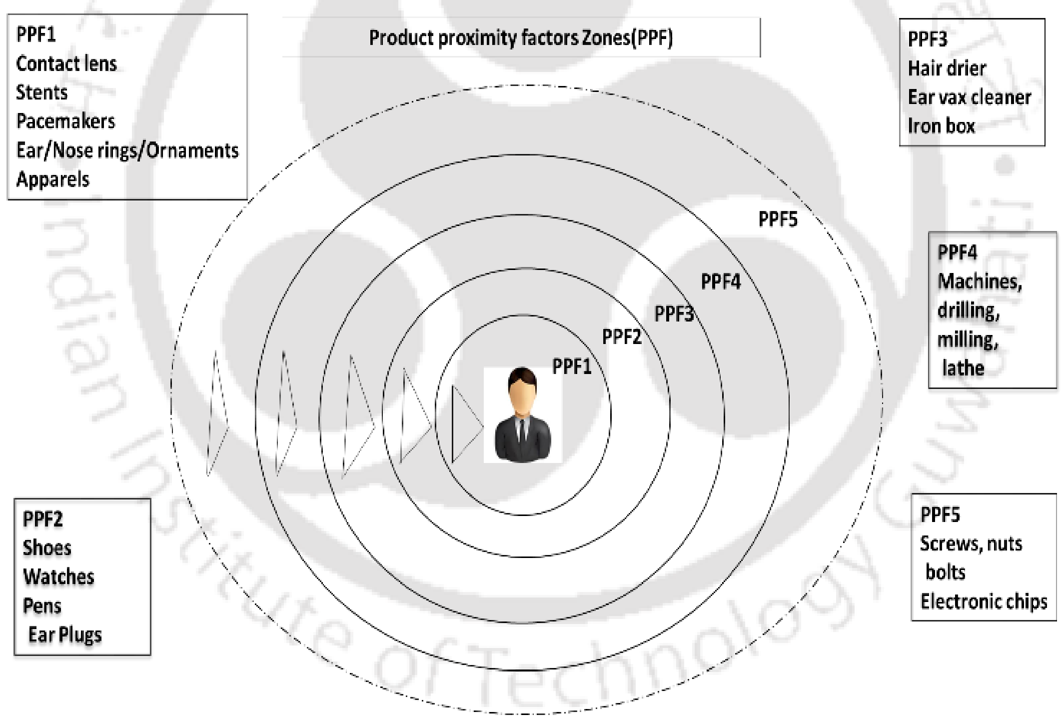


Figure 4.5 b: Product proximity factors zones adopted and redrawn from Yammiyavar, [2004]

The UCD approach goes beyond engineering optimized solutions thereby multiplying the chances of innovation becoming effective and successful in adding value beyond engineering. To add value, one needs to go beyond optimization boundaries. The words 'Design' and 'Innovation' are often used in place of each other in design discussions and discourses. Creative process in design are more associated with thinking, visualizing and imagination whereas Innovation as used in design is more associated with invention or incremental improvement in the physical features of a product. As part of validating the proposed innovation frame work, in this chapter two products have been subjected to design audit using UCD, usability and design space principles. The pilot studies will demonstrate how the subjective aspects such as aesthetics, ergonomics and usability have a role to play in the proposed innovation frame work. It is this important role that makes the proposed innovation frame work a novel and new contribution to addition of knowledge in this thesis.

To identify the variables influencing innovation in product design, the variables are studied and listed. As a qualitative aspect we are proposing a fractal triangle of innovation Fig. 4.7, based on the design space theory. All the identified design elements are mapped with ISO standards, which are discussed in the following sections.

Human factors are not new in product design, but its usage is infrequently and it is not considered as a standard practice in MSMEs, Veryzer, R [2005]. We should be able to trace back this role in the product part in designing phase. Our belief is that MSMEs can maximize innovation if design methodology with UCD is adopted and the same is depicted in Fig. 4.6. Hence, we are developing a frame work which incorporates the human centered or user centered design and identify the innovation index of the product.

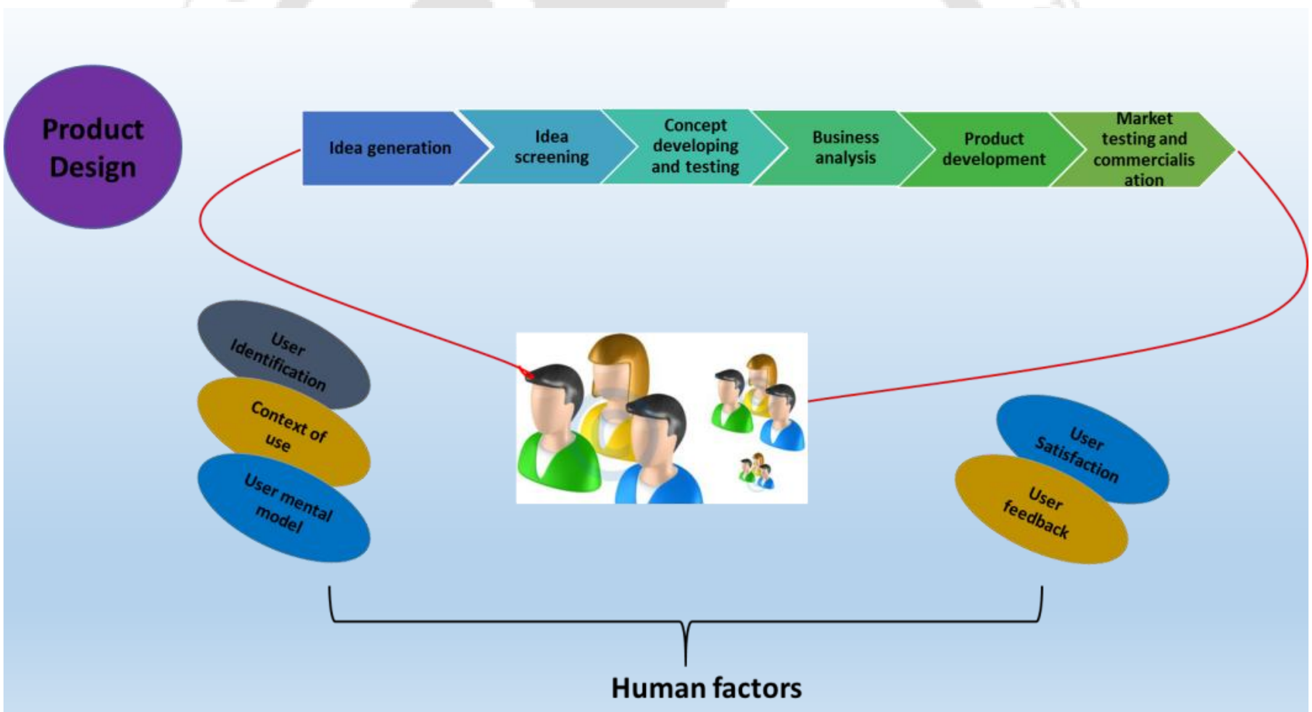


Figure 4.6: Human factors and product design cycle (Author Generated)

4.6.1 Number of variables involved add to complexity:

Based on the available literature and parameters influencing innovation, in the product design are identified. A 'novel fractal triangle of innovation' was conceptualized to express the variables, especially to suit the MSMEs requirements. It was developed as the existing design morphology and it did not answer the questions from the MSMEs perspective as shown in Fig. 4.7.

From design space theory, we developed a novel fractal triangle of innovation. We have identified some important parameters which influence the innovation and productivity in case of MSMEs and innovation can happen from any of these design elements, which are as follows:

4.6.2 Experiment Variables constituting fractal triangle of innovation:

Each parameter has sub parameters which are discussed in further sections. Based on literature parameters, sub parameters are identified from design and innovation point of view.

Table 4.3: All the parameters involved in the development of fractal triangle of innovation

Function	Aesthetics	Ergonomics	1st triangle
Usability	Form	Operations	2nd triangle
Manufacturing	Material	Construction	3rd triangle
Marketing	Margin	Maintenance	4th triangle
Public	Competitors	Policy	5th triangle
Logistics	Demand	Supply	6th triangle
Tools	New techniques	R&D	7th triangle

4.6.3 Proposed novel fractal triangle of innovation :

The proposed triagle of innovation is starting from the design space theory and developed over the identified parameters which leads to innovation if focused in the designing phase. Below Tables 4.4, 4.5 and 4.6 gives the sub-variables that need to be considered in the design phase by the designers and MSMEs, as they influence innovation.

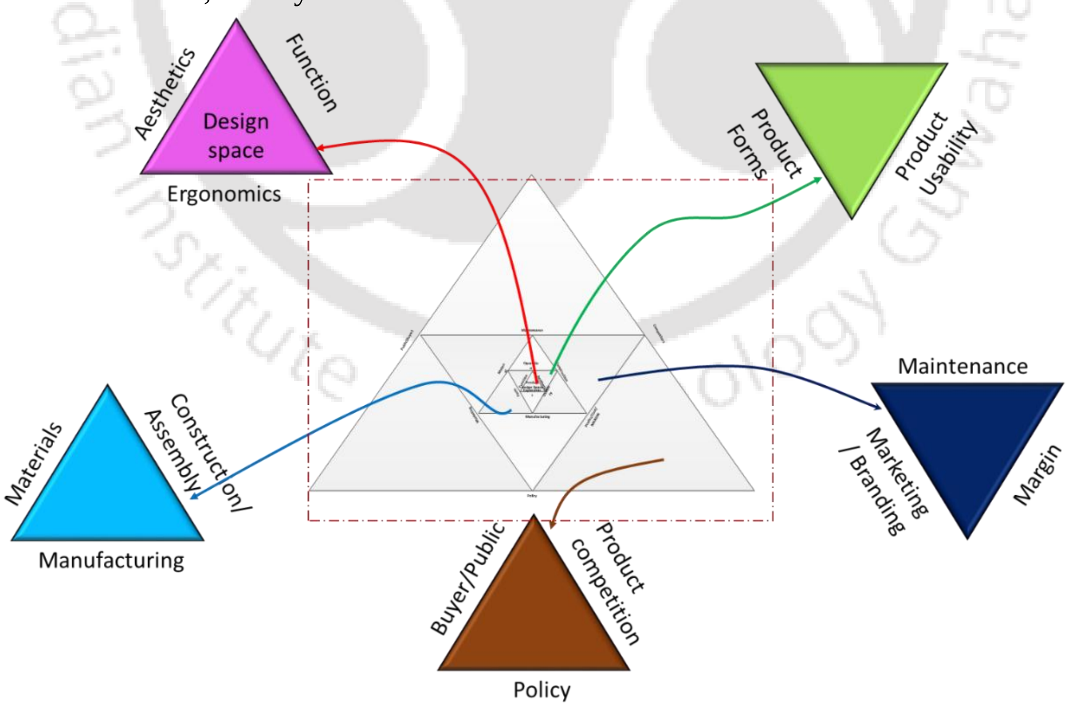


Figure 4.7: Proposed fractal triangle of innovation

Table 4.4: Parameters of the fractal triangle of innovation, that influence the innovation

Aesthetics	Ergonomics	Function	Usability	Material
Operations	Process/Manufacturing	Assembly	Maintenance	Margin/Profit
Marketing	Policy	Public/buyer		

Table 4.5: Variables forming the innermost triangle of design space

Aesthetics	Ergonomics	Function
Visual	Safety	Strength
Style	Efficiency	Durability
Color	Reachability	Cost/Value
Balance	Visibility	Purpose
Unity	Force	Fit
Symmetry	Duration	Features
Harmony	Anthropometry	Stability
Proportion	Repetition	Construction
Emphasis	Posture	Ease of Use
Rhythm	Direction	
	Glance	

Table 4.6: Second, triangle from fractal triangle of innovation and their design elements

Usability	Processes/Manufacturing	Operations
Functional	Human	Ease of use
Efficient	Machines	Handling
Error free use	Tools	Installation
Enjoyable	Equipment	Number of steps
Environment	Time	Practice
Economical	Cost	Operating
	Skills	Extra fits
	Power	Manual
	Space	Maintenance
	Assembly	

These design elements were listed based on the literature and few are commonly practiced by designers. The difficulty that persists, is the weightage factor that needs to be allotted to the design elements listed. There is no method for giving prioritization for the design elements. Hence, a method has been developed for this which saves time and effort as it acts like a template for these types of products. This has been discussed in the further section.

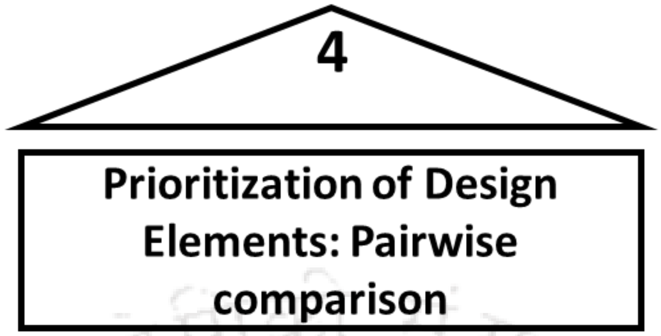


Figure 4.8: The basis for the prioritization of design elements

The above Fig. 4.8, shows the basis for prioritization, based on the number of variables involved in achieving innovation. As seen from novel fractal triangle of innovation, one can have account for the number of parameters involved. Hence, a pairwise comparison method is adopted in the innovation frame work.

4.6.4 Mapping of ISO Standards with design elements:

Mapping of identified design elements with ISO standards of usability have been done to ensure that the design space theory fulfills the ISO definition of usability and industrial design. The results of the mapping were found to be positive and fulfill the norms defined for usability. Hence, the frame work defined is robust in achieving innovation through the design space. Appendix C highlights the mapping of ISO standards with design elements chosen for study. Limiting values for each zone in product proximity, starting from 1 as ideal. This forms the bases on which we conceptualize our entire frame work of innovation. The values of Product Proximity Factor (PPF) zones have also been defined. A hand drawn mapping of ISO standards and design elements is discussed in detail in Appendix C.

In the product design phase while conceptualizing, a designer adopts heuristic evaluation to unfold the concept, defining all the while the specification of design ideas and elements. A framework of product's design space and boundaries as parameters [Yammiyavar, 2004] was adopted for the current study in prioritizing the aesthetics, ergonomics and function aspects of a product design space (Fig. 4.5).

Figure 4.9: The basis for HCD, Usability testing

Here, based on design space theory and design morphology we arrived at HCD. This was mapped with ISO standards to check its strong base discussed in Appendix C.

4.7 Selection of Design audit tools from available tools for incorporating them into the proposed frame work – Quantitative aspects

To choose from a wide variety of available tools one needs to setup an evaluation mechanism of these tools in terms of their capabilities to aid innovation of MSMEs. From chapter 2, under section 2.10 and 2.11 as part of literature survey, eight most frequently used and accessed tools were chosen based on their suitability criteria (Table 4.7) and frequency of use in literature. It was observed that no single tool covered all the variables that matter for innovation. Each tool has its own strengths and limitations. An evaluation criterion in Table 4.8 was proposed. These criteria were determined heuristically [liquisearch.com, 2016] based on their importance and ability to meet the needs of Indian MSMEs. The Ranking was done based on a scale of three. The evaluation question was, which of these tools are suitable for being adopted to improve innovation practices during product designing? Assuming that Indian MSMEs practice designing methods.

Table 4.7: Eight most commonly used tools are as follows

QFD	FBD	VE/VA	TRIZ	PDCA	SCAMPER	5W1H	DSM
Quality Function Deployment	**Fish Bone diagram**	**Value Engineering/ Value analysis**	**Theory of Inventive Principles**	**Plan-Do-Check-Act Cycle**	**Substitute, Combine, Adapt, Modify, put to another use, Eliminate, Reverse**	**What, Where, Who, When, Why, How**	**Design Structure Matrix**

The straightforwardness of heuristic assessment is advantageous at early phases of design. The Table 4.8 can be utilized to analyze suppositions amongst the tools and techniques by designers, engineers, practitioners and specialists. It will be valuable when choices are made on the premise of a few criteria which are recorded above and when a list of alternatives must be evaluated. For heuristics assessment, those proposed by Nielson's [2005], for example, afford a good match between the framework and adaptability, and between effectiveness of utilization and improvement. Weinschenk and Barker characterizations, such as simplicity, accuracy, user support and so on are utilized as needs to allocate the ranks to the chosen criteria. Along these lines in like manner high positioning criteria incorporate relevance, ease of use, solution time, usability, feasibility and applicability of the tools for MSMEs.

A significant part of the time in product design is recognizing the problem and characterizing it. Here the determination of tools and techniques is essential and ought to be such that it can be used in the initial phase of design, which is identifying and defining of problem. Higher weights will be given for the tools having potential in recognizing and characterizing the problems and having scope for innovation in product design.

The criteria that matter in the product design and innovation in MSMEs are identified and ranks are given based on their weightage. The identified criteria are mapped on the tools and evaluated. Further the results are shown in Table 4.8. We have used a scale of 3 for simple assessment.

Table 4.8: Evaluation criteria of the different tools and techniques with rankings

			1	2	3	4	5	6	7	8
	Criteria	**TOOLS**	**QFD**	**FBD**	**VE/VA**	**TRIZ**	**PDCA**	**SCAMPER**	**5W1H**	**DSM**
		Ranks	Meets need?	Meets need?	Meets need?	Meets need?	Meets need?	Meets need?	Meets need?	Meets need?
1	Relevance	3	3	3	3	2	3	3	3	2
2	Ease of use	3	2	2	1	1	2	3	3	1
3	Cost is less	2	3	3	3	2	2	3	3	2
4	Less Time	3	0	1	1	0	1	2	2	0
5	High Efficiency	2	2	2	2	3	3	2	1	3
6	Usability	3	3	1	2	1	0	1	2	3
7	Problem identify	2	2	1	2	2	2	2	2	2
8	Feasibility of solution	3	2	2	3	2	3	2	2	3
9	Applicable to MSME	3	2	3	2	2	3	3	3	2
10	Innovation competency	3	2	2	3	3	2	2	2	2
		Scores	**56**	**54**	**56**	**47**	**56**	**62**	**63**	**53**

Ranks: 3= Very important; 2= Important; 1=Less important meets need: 3= Very true, 2= Fairly well, 0= Not at all.

Table 4.9: Comparison and disparity amongst the different tools and techniques used in product design

Aspects / TOOLs	Idea generator	Idea pattern	Usability/ User centric	Knowledge base need	Relevance/ to MSMEs	Efficiency of the tool	Innovation competency	Operating /Solution time	Quality of Innovation Idea	Implemented at	Applicability/Idea into reality(Practice)
Quality function deployment (QFD)	Usually by group	Structured translates actual needs	Yes	Data base of needs is required	Yes	Very good	Systematic building blocks of functions	Average	Usually get feasible idea based on translated data	Initial stage of NPD or redesigning of product	Easy to workout
Fishbone diagram	Usually by group	Thinks in all direction	Yes	No	Yes	Very good	Systematic hierarchical set of factors for causes	Average	Usually get feasible cause and solution	Initial stage of NPD	Easy to workout
Value engineering (VA)	Usually by group	Structured improves value addition of the product	Yes	No	Yes	Very good	Analyze, understand detail of specific situation	Average	It gives the improved solution	Initial stage of NPD or redesigning of product	Easy to practice
TRIZ	Primarily individual	Stepwise scientific, logical	Yes, consider at initial stage	Powerful knowledge base needed	Yes	Very good	Follow the rules for innovation	Average	Usually can get a perfect idea based on the analysis	Initial to end stage of product design	Easy to implement as it is scientific
5W1H	Primarily individual	To the aspects of problem	No	No	Yes	Good	Systematic Questions	Less	Usually find the main conflicts	Initial stage of Product design	Depends on type of MSME
SCAMPER	Group thinking	Thinks in all direction	Yes	No	Yes	Good	Systematic Questions, divergence thinking	Less	Usually finds the solutions	Initial stage of PD	Relatively not Easy to implement
PDCA	Group thinking	Structured and improves existing products	No	No	Yes	Very good	It is continuous repetitive process	More(repetitive)	Better solution every time	Any stage of PD	Easy to practice
Design structure matrix	Usually group thinking	Structured translates actual needs	Yes	Yes	Yes	Good	Systematic building blocks of matrix	More	Usually finds the feasible solutions	Not in PD stage	Relatively not Easy to practice

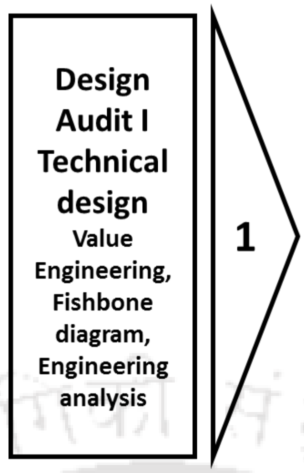


Figure 4.10: Technical design of parts and methods employed to audit them

Based on the literature survey, heuristic evaluation leads to identification of simple and usable tools out of available tools. Hence, this will be adopted in our frame work to understand, redesign and optimize the products that are manufactured by MSMEs.

The tools identified from above evaluation process for our study are FBD, VE, Usability testing, and Engineering analysis as represented in Fig. 4.10. As they are simple enough to work upon and have potential to cater innovation in the product design phase. These tools are well known to all and their executing time is less with no extra cost, or intensive training involved. Hence, we selected these tools and techniques for our experimental investigation.

It is observed that all aspects that influence innovation are not present in a single tool. Therefore, there is a need for a combinatory approach if one must come up with a comprehensive frame work for innovation - specific to MSME’s. Much of innovation can happen through good design. An optimized innovation tool will therefore have equal importance and equal chance for innovation to happen in the overall aspect of the product.

When the frame work is developed and combined as shown in Fig. 4.11, from above discussion, the basis of each component in the proposed innovation frame work is understood.

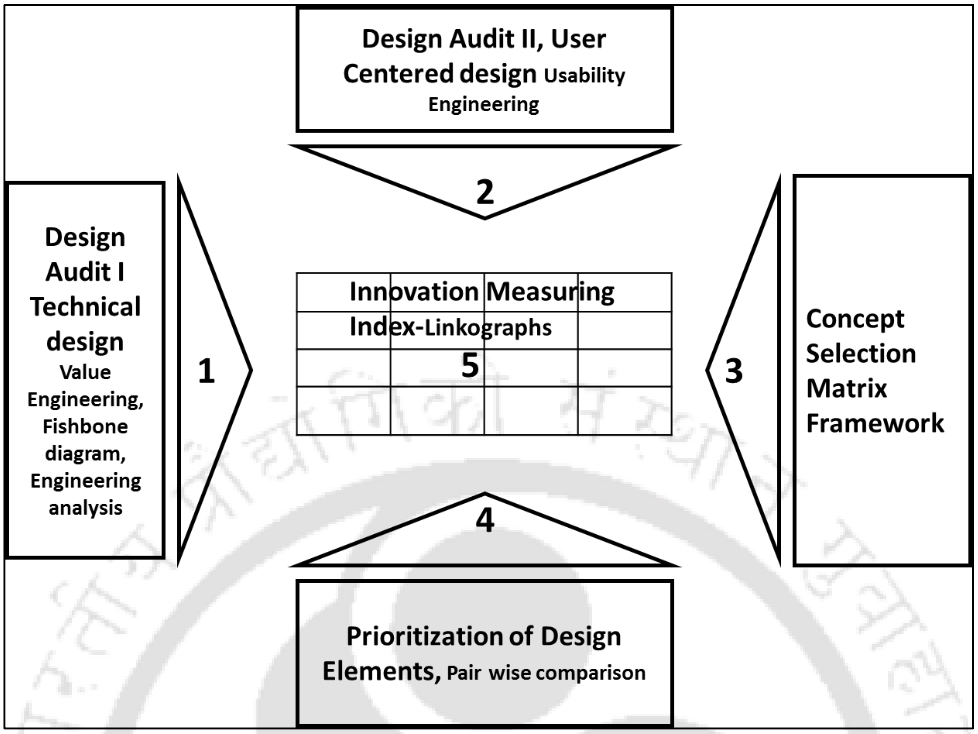


Figure 4.11: Proposed frame work for innovation

Towards the development of the innovation frame work proposed in Fig. 4.1 at the beginning of this chapter. The Fig 4.8, 4.9 and 4.10 shows the initial stage of development of the main frame work. We propose a framework (Fig. 4.11) which will help MSMEs to incorporate innovation in product design. The concept selection matrix will lead to final design for manufacturing of products. Linkographs, a measure of innovation index is planned to be the central matrix of the proposed final innovation frame work (Fig. 4.11).

In developing the main frame work, initial thought process in the form are as follows. The innovation influencing parameters are followed by a filter which acts as the indicator for considering, need, capacity of MSMEs, their capabilities and design consideration Fig. 4.12. Plan and action are expected to lead to multiple alternate solutions ensuring maximum innovation probability Fig. 13.

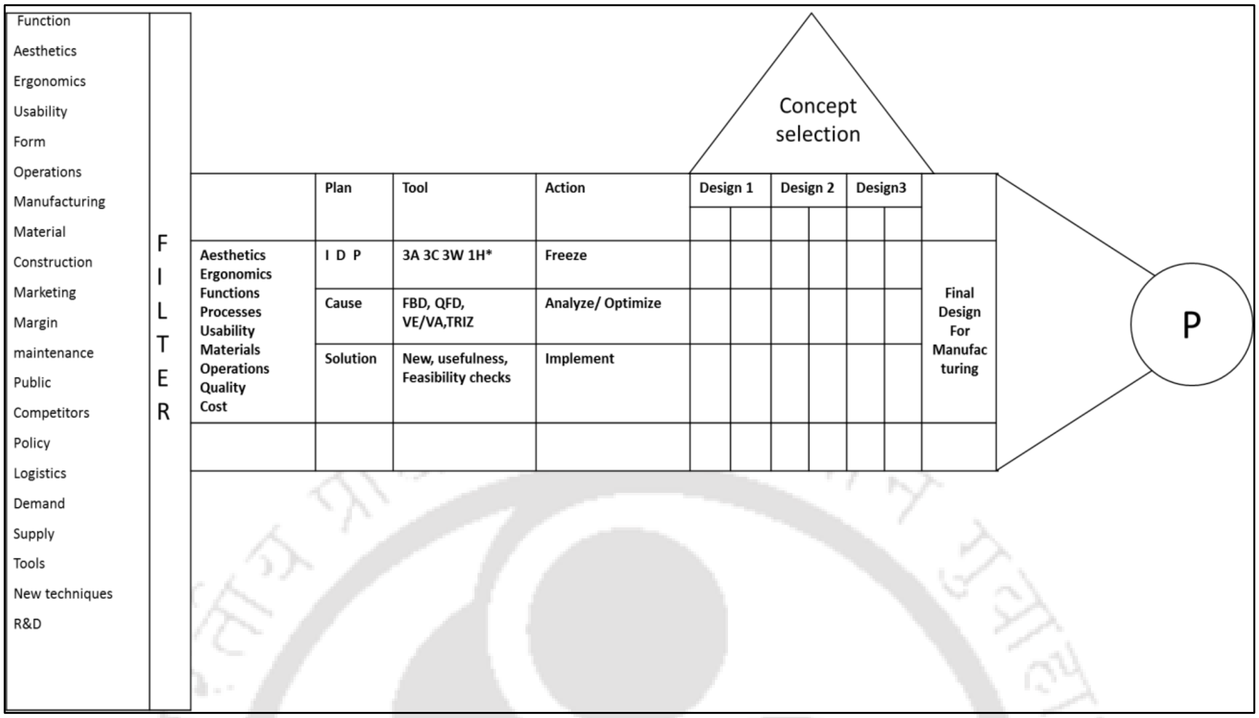


Figure 4.12: Shows the proposed conceptual frame work for product design tool for MSMEs

Further, a plan of action for developing the conceptual frame work is shown in Fig. 4.13 below.

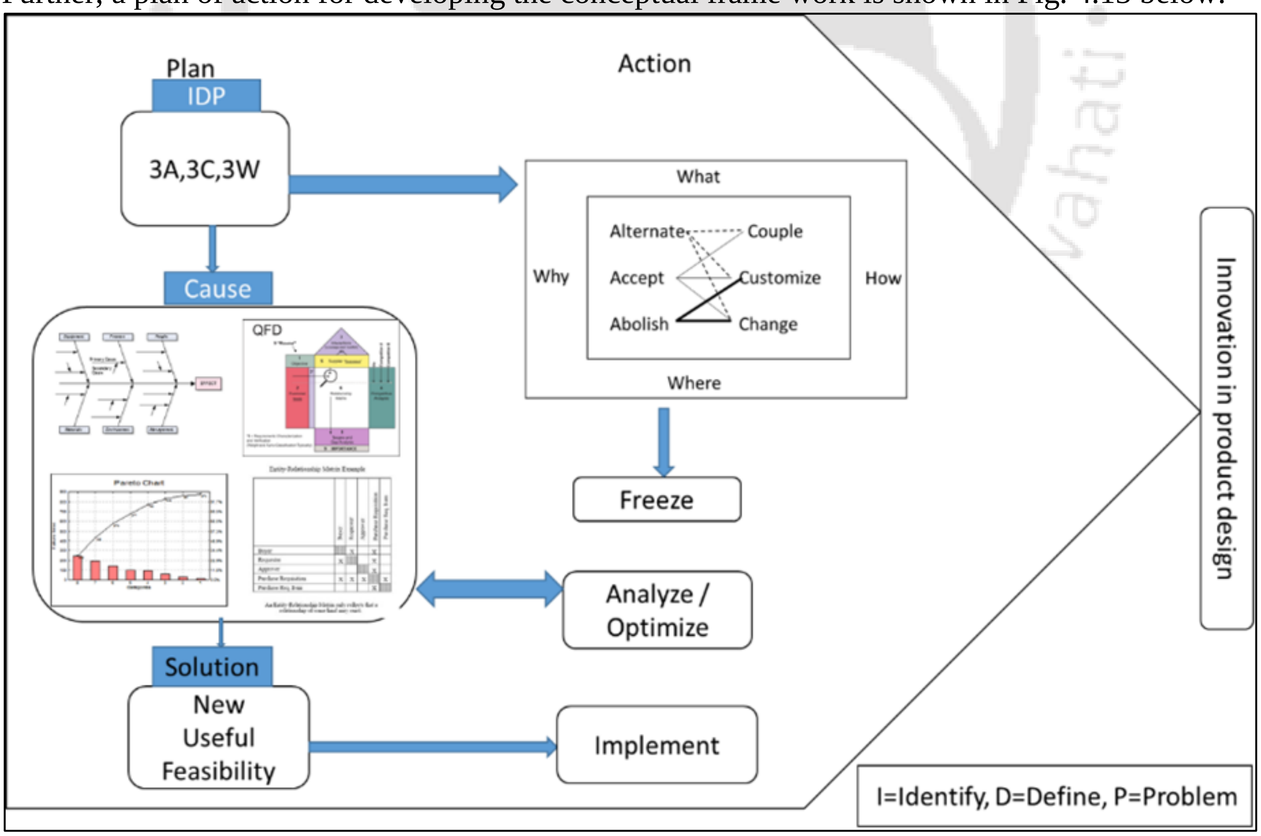


Figure 4.13: Plan and action cycle for the conceptual frame work proposed

Based on literature, study of existing product design tools was carried out to gauge their suitability to be used by MSMEs for purpose of innovating products manufactured. It was observed that no single tool or method could be used effectively in isolation. Hence, using a combinatorial approach, a new proposal in the form of a frame work that incorporated existing tools/methods was made. The proposed frame work (reproduced in Fig. 4.11) is expected to aid MSMEs to quickly adopt new design thinking paradigm with which innovation can be made part and parcel of their strategy.

4.8 Pilot Testing of the proposed Innovation Frame work

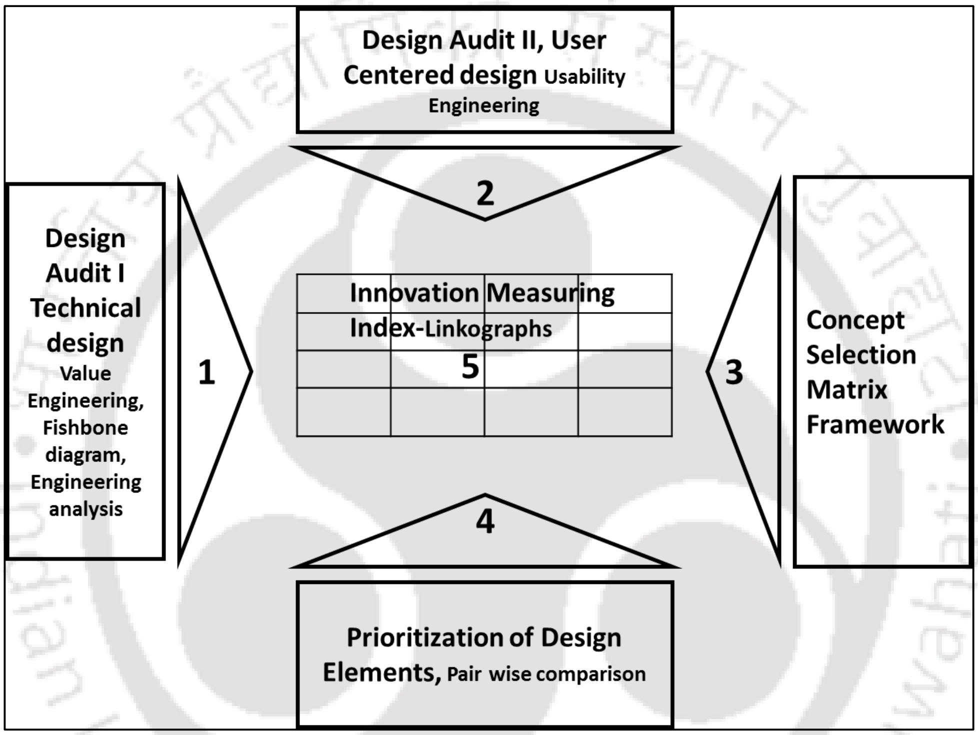


Figure 4.14: Proposed innovation framework

Proposed innovation frame work consisting of qualitative aspect auditing tools and quantitative aspects auditing tools (Fig. 4.14) must be tested for its reliability and validity.

Two products, both manufactured by MSMEs have been chosen randomly and subjected to design auditing using the proposed innovation frame work. The two products are:

a) Electric Earwax Remover and
b) Automatic solar vent cooler for parked automobiles.

The identified products fall under PPF zone 3. The design audit of ear wax remover and solar powered automatic vent air cooler of a car is used for pilot study. Possible improvements in the product are observed and inferred in the design audit. For ranking the order and assigning weights, pairwise comparison method is utilized [Dym, et.al., 2002], in which each design variable is compared with each other.

4.8.1 Description of Product Sample Earwax Remover: An effective and safe way of cleaning and drying ears to remove wax. It works on gentle suction principle. Cotton swabs push wax and debris further inside the ear, which can harm the ear drums. This product gently draws dirt particles and moisture out of the ear by suction. It is powerful, yet gentle, it features an examining light on the tip and is cordless as it uses batteries for operation. Safety guard prevents tip from entering too far into the ear. Easy, safe and effective cordless features make it handy and raises its usability quotient.

In the process of design audit, we identified problems such as it is not 100% effective in removing wax from the ear. More attention is needed during usage, especially the placement of on/off button, needs a proper design of the grip/handle for making it sturdy and steady. There persists a problem of the nontoxic silicon tip detaching inside the ear. Suction is low, and produces noise while operating. Apart from this customer feedback was recorded from the seller's e-commerce website. The Fig. 4.16 represents the task process flow diagram and Fig. 4.18 shows the Fishbone diagram.

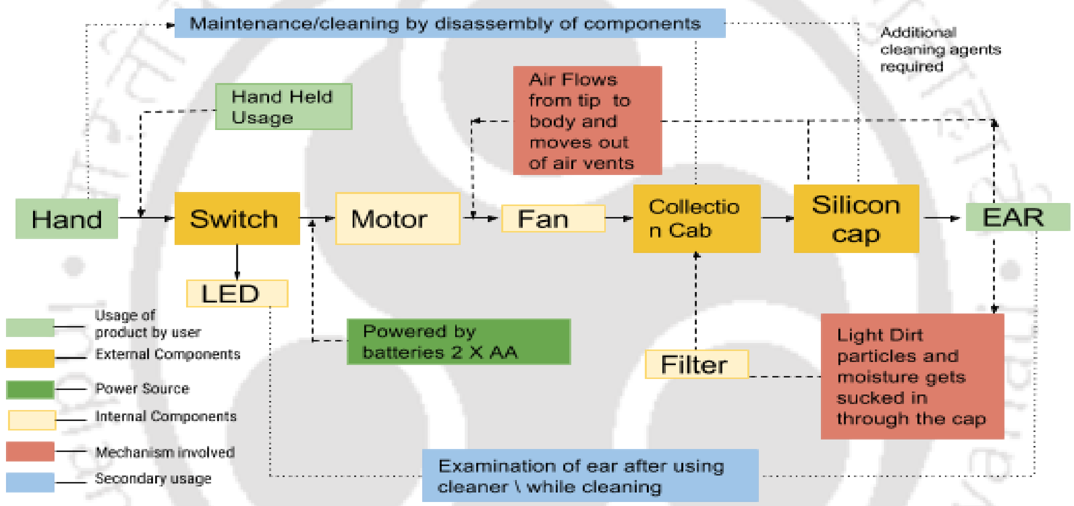


Figure 4.15: Product task process flow diagram Earwax Remover

Figure 4.16: Earwax Remover product with its parts as part of reverse engineering

As a part of the process, disassembly of the product is carried out along with identification of parts as in Fig. 4.16 which helps in calculations of value engineering as described in Table 4.11.

4.8.2 Fish bone diagram of Product Sample Earwax Remover

This component of analysis focuses on technical design to understand the product in all aspects of design. As a part of design audit I, it is contributing to technical design.

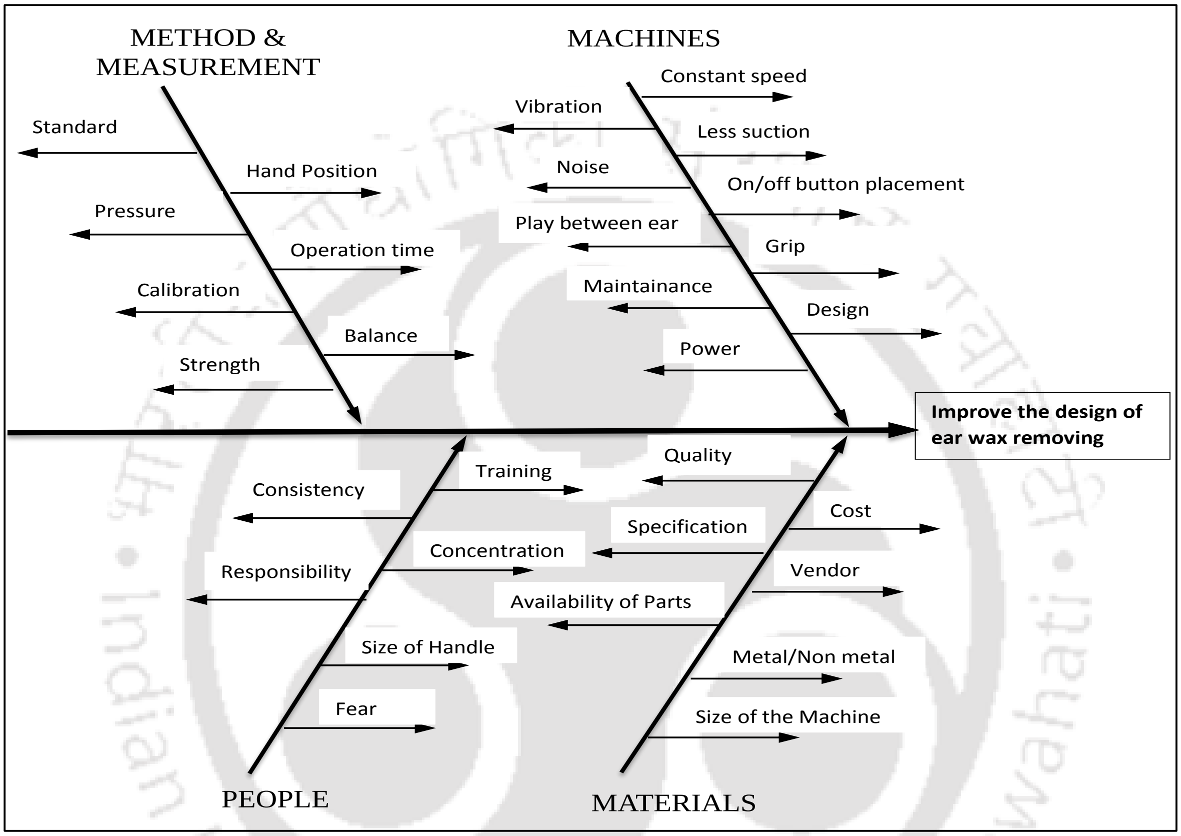


Figure 4.17: Fish bone diagram for the Earwax Remover, in which we can identify problems

From the fish bone diagram, we can identify the positive and negative points about the product. We could identify the areas of improvement so that those can be eliminated in the redesigning phase. It gives the designed features and consistencies with respect to user and it gives the overall view of the product.

4.8.3 Value analysis of Earwax Remover

This component of analysis is focusing on technical design to understand the product in terms of cost to function. As a part of design audit I, it is contributing to technical design.

Value analysis is a systematic method to improve the "value" of products and services by using an examination of function. Value, as defined, is the ratio of function to cost. In this case the whole product is disassembled, labeled, photographed, listed its function, cost and need of alteration etc., which will give priority of redesign based on the cost of the component and its function. In this case it is possible to reduce the cost, improve the product by changing the design and keep the function unaltered.

Table 4.10: Results of Value engineering for Earwax Remover

Sl. No.	No of Parts	Component	Function	Material	Importance to customer	Cost in Rs.	%	Need of alteration and reason	Priority of redesign
1	1	Nontoxic silicon tip	-Tip goes inside the ear, touches the deeper walls of the ear canal -Acts like a vent pipe -Waste comes from this smooth tip	Silicon rubber	-High -High - Medium	3	0.66	Yes, As there is fear of sticking the tip inside the ear canal	7
2	1	Safety guard	-Acts as a stopper - Limits the insertion of tip by touching to the pinna (exterior of ear)	Soft rubber	-High -Medium	8	1.78	No	6
3	2	Filter and waste collection cabin	-Covers the impeller -Stops waste to enter in to the suction chamber -Dome shaped space for waste collection -Nozzle provides the seat to the silicon tips	-Aluminum sieve with plastic -Plastic	-Low -Low -Low -Low	40 20 5	8.88 4.44 1.11	No	3
4	1	On/off button SPDT	-Connecting the circuit -Start the DC motor -Impeller causes suction which takes out the waste	Plastic and copper lining with wires and circuits	-High	10	2.22	Yes, as it is complicated and can be replaced with simple push button (spring, slider, balls etc.)	5
5	1	Grip/Handle	-Holding -Steady holding, while using	-Plastic	High	60	13.33	Yes, it is not designed ergonomically. Shape, size need to change	2

			-Space provided for the switch -Underneath space for batteries						
6	1	9 V DC Motor 1.5 V 2 batteries	-Generating rotation -Battery power converted to impeller rotation	Plastic and metal	Low	150	33.33	No	1
7	1	LED Light	-Emits light -Helps in observing inside the ear by others	-Fiber metal	Low	2	.44	No, but it can be eliminated as it’s not possible for the user to see inside the ear when light is on	8
8	1	Full Body	-It is the space in which all parts are assembled -It is in two halves -Protects all parts -Protects the user -Improves aesthetics	Plastic	Medium	45	10	Yes, It can be done made by press fit	4
Other parts in assembly A. Impeller B. Motor holder C. Batteries attachment and cover D. Screws 3									

The total cost of the product is Rs. 450/- in online shopping sites. For a cost estimation individual parts prices are checked in websites and evaluated. For some parts, it is calculated based on material, process etc. Some other problems that are examined are as follows: Not much suction, Noise, play between ear and tip, fear etc. To be a successful product, it should focus on the user, innovative, cheaper and with better functionality. So, to improve the existing product performance, we will redesign some of the parts based on the value analysis.

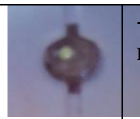
4.8.4 Engineering analysis of product Earwax Remover

This component of analysis is focusing on technical design to understand the product in engineering aspects of product design. As a part of design audit I, it is contributing to technical design.

It involves the application of scientific analytical principles and processes to reveal the properties and state of a system, device or mechanism under study. Here the number of components, material, dimensions, processes, costing and total unit costs are calculated to understand the opportunities for value addition. Apart from this, stress-strain calculation can be included along with the life of the product.

Table 4.11: Results of Engineering analysis for Earwax Remover

Sl No	Component	Figures	Material	Process	Volume	Fixed costs	Variable costs	Total Unit Cost in Rs
1	Nontoxic silicon tip		Silicon rubber	Injection molding	1	1	2	3
2	Safety guard		Soft rubber	Injection molding	1	1	7	8
3	Filter and waste collection cabin		-Aluminum sieve with plastic -Plastic	Injection molding	2	5	35 20 5	40 20 5
4	On/off button SPDT		Plastic and copper lining with wires and circuits	Assembly of many electric parts, wires, seals, holders etc.	1	1	9	10
5	Grip/Handle		-Plastic	Injection molding	1	20	40	60
6	9V DC Motor 1.5V 2 batteries		Plastic and metal	Assembly of many electric parts, wires	1	50	100	150

7	LED Light		-Fiber material		1		2	2
8	Full Body		Plastic	Injection molding	1	5	40	45

(In the thesis direct total cost is calculated)

$$\textbf{Product Unit cost} = \frac{\textbf{Total direct labor+Total direct Materials+Consumables supplies+Total allocated overhead}}{\textbf{Total number of units}}$$

…Equation 3

Fixed costs: These costs are always there in any product i.e. plant, current, heat, rent, lights etc.

Variable costs: These includes things like raw materials, labor cost and total cost of manufacturing [Ulrich, K. T. 2003]; [smallbusiness.chron.com, 2016].

Total cost = Fixed cost + Variable cost

4.8.5 Usability test of Earwax remover

This component of analysis is done under UCD and Usability engineering, in order to understand the product and user perception. As a design audit II, it is contributing to design.
Usability audit is carried based on the 5 E principles, which leads us to record the user's perception. What should be the improvement needed to satisfy the user? How close is the product towards the user? As shown in the table below, from a usability audit, we can identify problems with the product from user's point of view. The test was conducted by professionally trained design students as a part of their assignment. 30 participants were involved and results were recorded and summary is formulated in Table 4.12.

Table 4.12: Results of Earwax Remover when usability test conducted

Parameter	**Details**	**Remarks/Problems**
Product Identification	Earwax cleaner	
User Identification		Any one above age 10 can use
Environment	Workspace Work surface	1. Most of the time bedrooms. 2. In bathroom and in front of mirror.
Effectiveness to use Functional	Features Limitation Consequences	1. Not 100% effective. More attention is needed. 2. Difficulty in using as the on/off button is not proper. 3. Needs proper design of the grip/handle 4. Chance of detaching the nontoxic tip inside the ear.

		5. Suction is low. 6. Produces noise while operating.
Efficiency to use Efficient	Usable	Average ratings given by the variety of customers and users.
Error free in use Safe	Safety	1. Fear of detaching tip inside the ear; 2. Grip is also not ergonomically designed. 3. Confusion in setting one off while usage. 4. Fear of kids may get hurt ear canal
Easy to use Friendly	User-friendly	1. Easy to use, anyone can operate easily, kids can use under adult supervision. 2. No need of training or manual. 3. All parts can be detachable.
Enjoyable in use Pleasurable	User Experience	Not up to the mark as in commercials. Variety of colors can be added, soft grips, attachment of smooth trimmer for facial hair. remover, Digital clock can be placed.

4.8.6 Prioritization of variables is cumbersome

We started by trying to find interrelationships between the various variables that go into the product's design. Designers and MSMEs are unaware of the degree of prioritization and weightage that has to be given while in the design stage. In achieving this, we adopted bipartite graph, Digraph and pair wise comparisons methods to the products analyzed as a pilot study. Pairwise comparison helps in prioritizing design elements. The total sum of the individual element's contribution in design are converted into a percentage based on the weightage. Based on the prioritization of the design elements we are able to give weights to them, which formulate a readymade template for these kinds of products.

The pairwise comparison method allows one, to determine the relative ranking of the group of items. It is often used as part of a process, assigning weights to criteria in design concept development. The design parameters were listed based on the literature study for aesthetics, function, ergonomics distinctively [Dym, et.al.,2002] and [Bossuyt & Patrick 2012].

Recollecting the proposed innovation frame work, in reverse way now as for existing designed product we are prioritizing the design elements, i.e. by backward integration of the design and hence the frame work also can be used in reverse way.

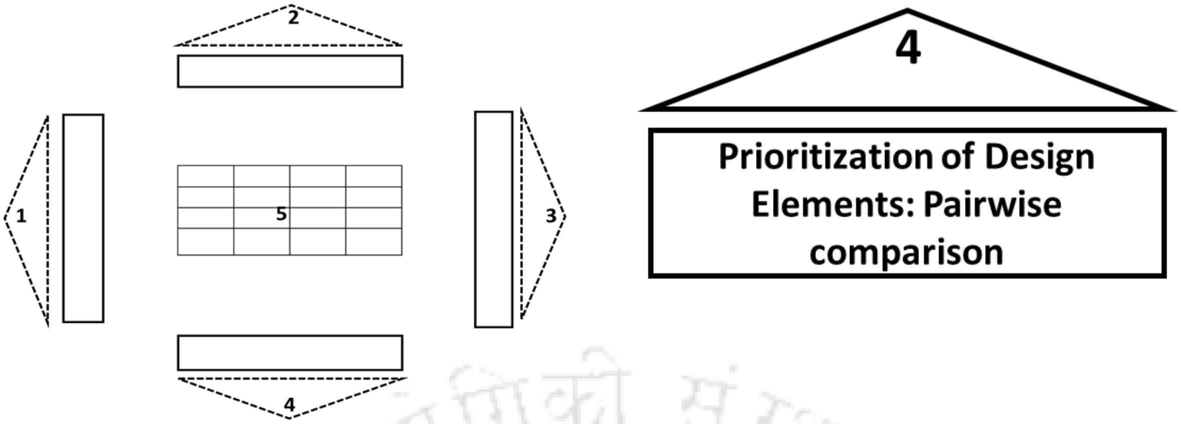


Figure 4.18: Proposed frame work when reversed can be integrated backwards in designing

Table 4.13: Weightages and prioritized elements of Ergonomics and Pairwise comparisons

Ergonomics

	Posture	Anthropometry	Reachability	Visibility	Direction	Glance	Duration	Repetition	Force
	A	A	C	A	A	A	G	H	I
		B	B,C	D,B	B	B	G	H	I
			C	C,D	C	C	C	H	C
				D	D	D	G	H	I
					E	E	G	H	I
						F	G	H	I
							G	H	G
								H	H
									I

Sl no	Parameters	Total score
A	Posture	4
B	Anthropometry	4
C	Reachability	7
D	Visibility	4
E	Direction	1
F	Glance	0
G	Duration	5
H	Repetition	8
I	Force	5

Priorities Based on scores	% Weightage
Repetition	21.04%
Reachability	18.41%
Duration, Force	13.15%
Posture, Anthropometry, Visibility	10.52%
Direction	2.63%
Glance	0%

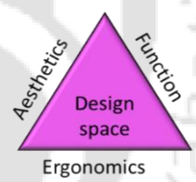


Table 4.14: Weightages and prioritized elements of Aesthetics and Pairwise comparisons

Aesthetics

	Unity	Symmetry	Balance	Rhythm	Color	Harmony	Emphasis	Visual	Proportion	Style
	A	A2	A2	A1	E2	A1	A1	H2	A1	J2
		B	B2	B2	E1	F1	B1	H2	B2	J2
			C	C2	E1	C2	C2	H2	C1	C2
				D	E2	D1	G1	H1	I2	J1
					E	E2	E1	H2	I2	J1
						F	F2	F2	F1	J1
							G	H2	I2	G1
								H	H2	J1
									I	J2
										J

Sl no	Parameters	Total score
A	Unity	8
B	Symmetry	7
C	Balance	9
D	Rhythm	1
E	Color	9
F	Harmony	6
G	Emphasis	2
H	Visual	13
I	Proportion	5
J	Style	10

Priorities Based on scores	% Weightage
Visual	20.19%
Style	16.3%
Color, Balance	14.67%
Unity	13.04%
Symmetry	11.41%
Harmony	9.78%
Proportion	8.15%
Emphasis	3.26%
Rhythm	1.63%

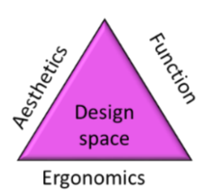


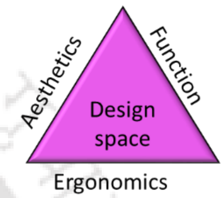
Table 4.15: Weightages and prioritized elements of Function and Pairwise comparisons

Function

	Need	Features	Value	Strength	Durability	Safety	Efficiency	Stability	Construction	User friendly	Cost	Ergonomic fit
	A	A3	A2	D2	E1	F3	G3	H1	A2	J2	K2	A2
		B	B2	D1	B2	F2	G2	H1	B1	J1	K1	B2
			C	C2	E1	F2	C2	C2	C2	I1	K2	L1
				D	E2	F2	G2	H1	D2	J2	K2	L2
					E	F2	G2	E,H	E	J1	E	L2
						F	F3G3	F2	F1	F2	F2	F2
							G	G2	G1	G2	K2	G,L
								H	H1	J2	K2	I2
									I	I3	K2	I2
										J	K1	L2
											K	K1
												L

Sl no	Parameters	Total score
A	Need	9
B	Features	7
C	Value	8
D	Strength	5
E	Durability	6
F	Safety	23
G	Efficiency	17
H	Stability	5
I	Construction	6
J	User friendly	9
K	Cost	15
L	Ergonomic fit	9

Priorities Based on scores	% Weightage
Safety	19.32%
Efficiency	14.28%
Cost	12.67%
Need, User friendly, Ergonomic fit	7.56%
Value	6.72%
Features	5.88%
Durability, construction	5.04%
Strength, stability	4.22%



In design audit, the variables involved are prioritized based on pair-wise comparison. The variables are then used in the next step. This would be improving the product through generating multiple solutions or entirely new product with the function being unaffected. Out of the generated concepts arise a question which one must be selected? which one is more value added? In answering these questions, we have used simple and easy matrix framework for concept selection as discussed in the section 4.5.

4.8.7 Design audit results, lead to the problems/defects in the product

- Each of these parts have the potential for redesigning and improving.
- For any product, it is possible to exactly identify the part/component that has maximum potential for innovation, it can then be stretched further to add value in the product.
- It is not only engineering; the value addition is from the user point of view.

Based on possible solutions for incorporating innovation of those parts (It may be reduction, material improvement of component etc.), some concepts are generated considering all above experimental details. Further, we have developed a framework such as concept selection matrix, which is simple and effective to use, so that MSMEs can adopt, use and add value to their products.

Some of the concepts generated during the study are shown in Fig. 4.19.

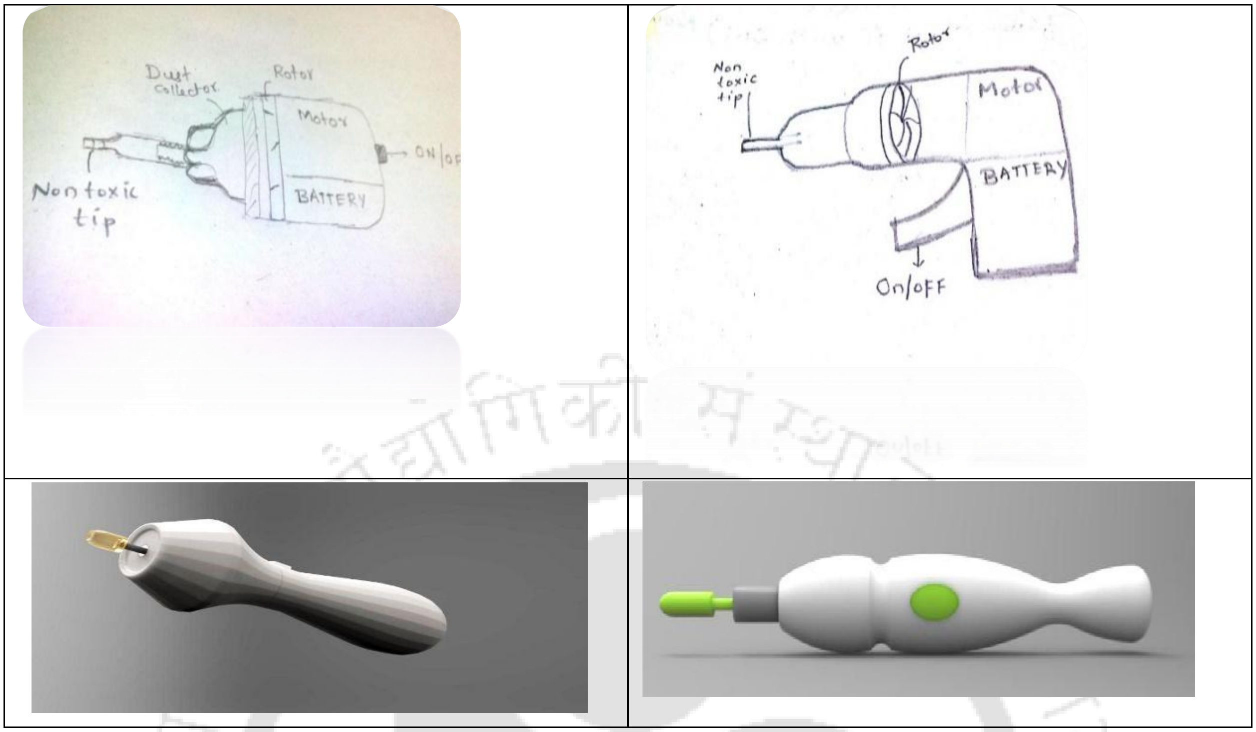
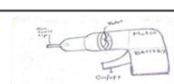
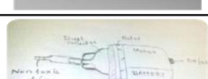


Figure 4.19 New Concepts generated during the designing phase

Out of the generated concepts we need to select the best concept that had more value addition. This was done based on the generated matrix frame work as shown below in Table 4.16.

Table 4.16: Shows the ranking of the concepts generated

		Design Methods Applied	Degree of newness		Design Criteria (strong=9; medium=3; weak=1)								Sheer Innovation Prospect	Rank
				Criterion weightage	9	9	9	9	9	9	3	3		
Problem 1: Ear wax remover					Low Cost	Light Weight	Efficiency	Functionality	Good ergonomics	Ease of use	Maintenance	Less process time		
Case 1														
Design1		Brain storming	3		3	3	9	9	3	9	3	9	360*3	2
Design 2		SCAMPER	3		9	3	9	3	9	9	9	9	432*3	1
Design 3		SCAMPER, linkograph	1		1	9	3	3	9	3	3	3	270*3	3

As seen from the above table, the design 2 has a higher ranking. Hence, this concept is selected, out of the generated concepts for further steps as prototyping and final product for production.

4.9 Pilot Study 2: Solar powered auto vent cooler for the car

4.9.1 Product description of solar powered auto vent cooler for the car: It is a solar powered fan that keeps the interior of the car cool and fresh. The solar panels on the outside collect and use the sunlight to run the fan that is on the inside. It sucks out the hot air that is inside the car and replace it with the cooler outside air current. It can reduce the use of air-conditioning and it fits any car model. The problems observed during the study and customer feedback from sellers revealed difficulty in closing the window completely. Without direct sunlight it will not work (will not be effective for tinted glasses) and suction capacity is very low for bigger volume cars.

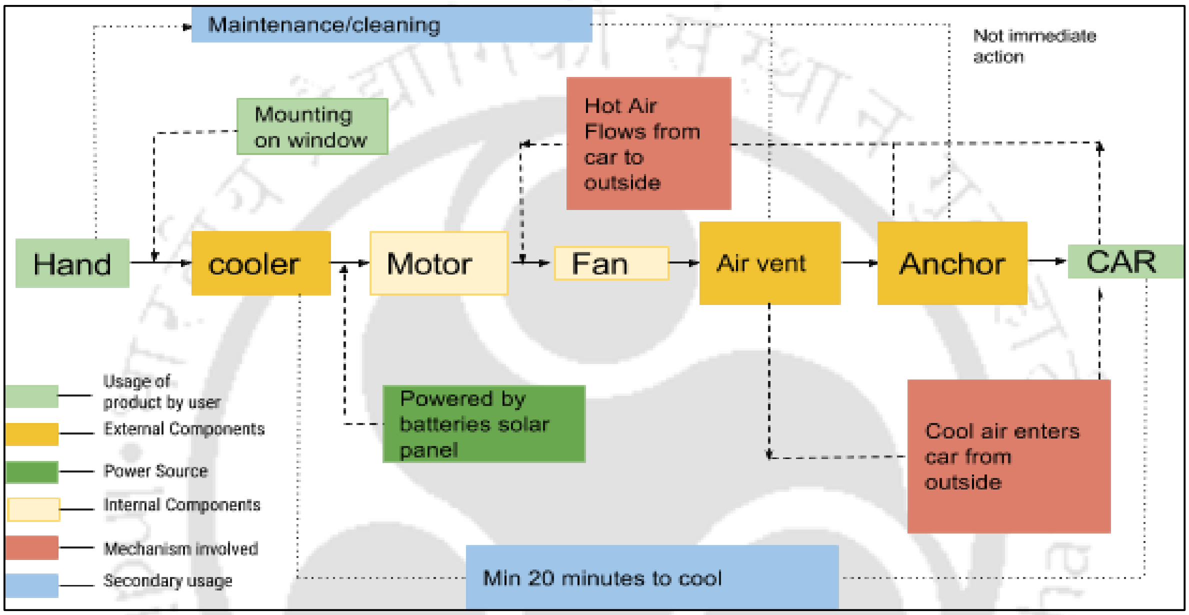


Figure 4.20: Product task process flow diagram Solar powered automatic vent air cooler

Figure:4.21: Solar powered auto vent cooler for the car

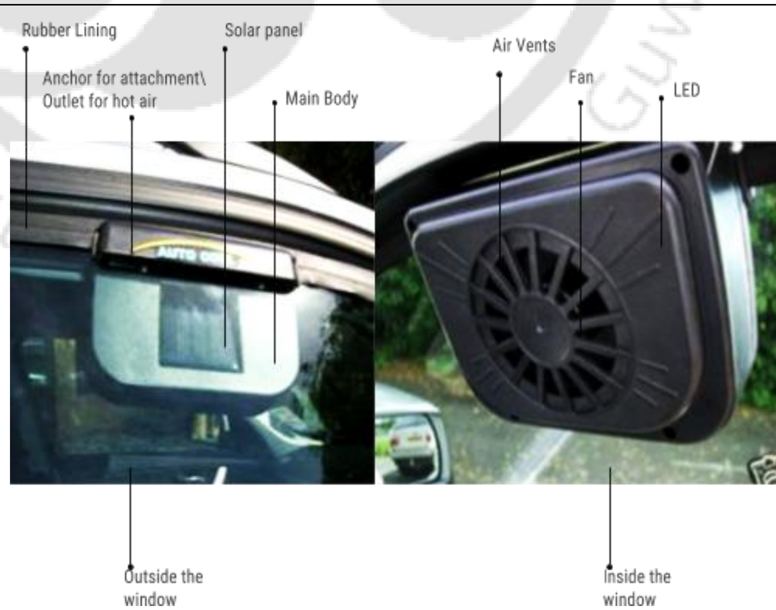


Figure 4.22: Solar powered automatic vent air cooler for the car with its parts as part of reverse engineering

4.9.2 Fish bone diagram of Solar powered automatic vent air cooler for the car

This component of analysis focuses on technical design to understand the product in all aspects of design. As a part of design audit I, it contributes to technical design.

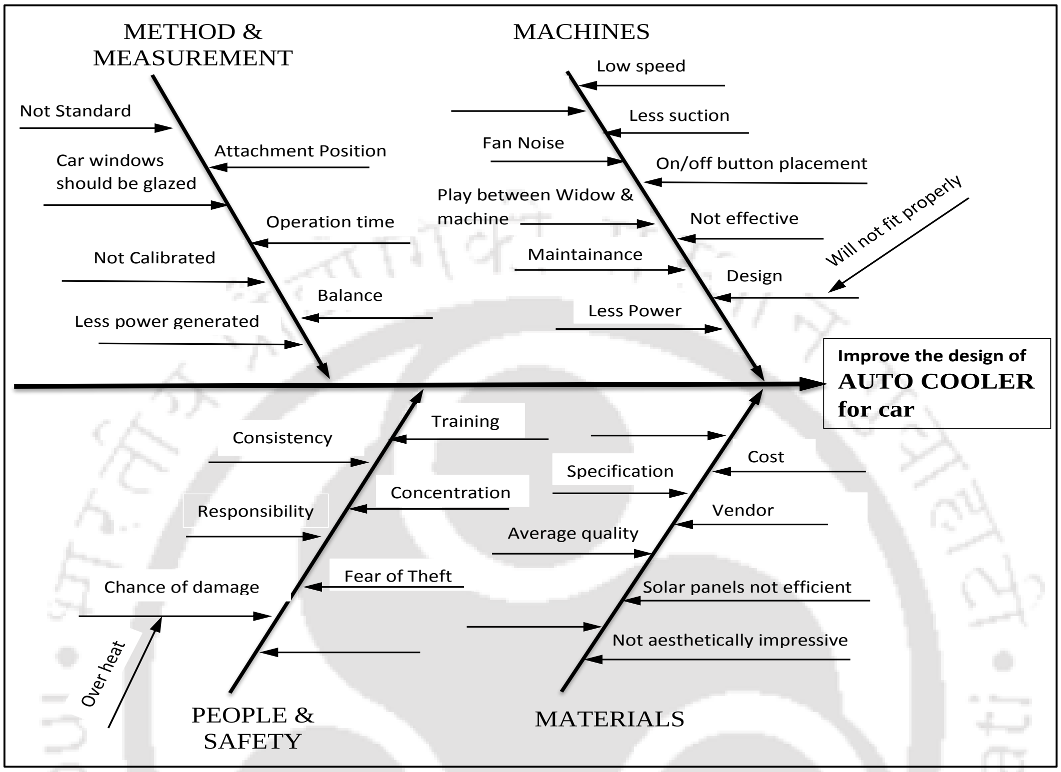


Figure 4.23: Cause and effect analysis represented through fishbone diagram of Solar powered automatic vent air cooler

4.9.3 Value analysis of Solar powered automatic vent air cooler for the car

This component of analysis is focusing on technical design, to understand the product in cost to function. As a part of design audit I, it contributes to technical design.

It is a systematic method to improve the "value" of products and services by using an examination of function. Value, as defined, is the ratio of function to cost. Here, the whole product is disassembled, labeled, photographed, listed its function, cost and need of alteration etc. This will prioritize the design based on the cost of the component and function. Therefore, we can reduce the cost, improve the product by changing the design and keep the function unaltered.

Table 4.17: Value engineering and Value analysis of the Solar powered automatic vent air cooler for the car

Sl. No.	No of Parts	Component	Function	Material	Importance to customer	Cost in Rs	%	Need of alteration and reason	Priority of redesign
1	1	Rubber lining	-Closing the window	Rubber	High	10	3.7	Yes	4

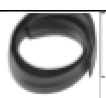
2	1	Anchor	Hooking to the sliding window	Plastic	Medium			Yes, alternate arrangement for clamping	
3	1	Air vent	Passing the hot air	Plastic	Medium			No	
4	1	Fan	-Suck the hot air and pass it outside	Plastic	-Low	25	9	No	3
5	1	Solar panels	Generate the current to rotate the fan	Silicon	Low	50	18.8 6	No	2
6	1	Outer casing	-Casing for all the components	Plastic	Low	80	30	Yes, alternate arrangement for clamping	1
7	1	Circuit	PCB	Copper and bread board		50	18.8 6	Yes, automatic starting of fan has to be stopped	2
8	1	Motor	Multiple components			50	18.8 6	Yes, High speed motor to be designed, based on the size of the car	2

4.9.4 Engineering analysis of Solar powered automatic vent air cooler for the car

This component of analysis focuses on technical design to understand the product in engineering aspects of product design. As a part of design audit I, it contributes to technical design.

It involves the application of scientific analytical principles and processes to reveal the properties and state of a system, device or mechanism under study. Here number of components, material, dimensions, processes, costing and total unit costs are calculated in order to understand the opportunities for value addition. Apart from this, stress-strain calculation can be included along with the life of the product.

Table 4.18: Showing the Engineering Analysis of the auto vent cooler for car

Sl. No .	Compone nt	Figures	Material	Process	Volu me	Fixed costs	Variable costs	Total Unit Cost in Rs.
1	Rubber Lining		Rubber	Injection molding	1	2	8	10
2	Anchor		Plastic	Injection molding	1			
3	Air vent and Fan unit		- plastic	Injection molding	2	5	20	25

4	Solar Panel And wiring circuit		Silicon Cu wiring with plastic lining	Assembly	1	20	130	150
5	Body		- plastic	Injection molding	1	20	60	80

4.9.5 Usability test of Solar powered automatic vent air cooler for the car

This component of analysis focuses on user centered design, usability engineering, understanding the product and user perception. As a design audit II, it is contributing to user centered design. Usability audit is carried based on the 5 E principles, which leads us to record the user's perception. What should be the improvement needed to satisfy the user? How close is the product towards the user? As shown below in Table 4.19 from a usability audit, we can identify problems with the product from user's point of view.

Table 4.19: Usability test results of the auto vent cooler for car

Parameter	**Details**	**Remarks/Problems**
Product Identification	Auto Cooler Solar Powered Fan Ventilation System for Car	
User Identification		Any one above age 18
Environment	Workspace Work surface	1. In cars during summer season. 2. At windows clamping the unit.
Effectiveness to use Functional	Features Limitation Consequences	1. Not 100% effective. 2. Difficulty in closing the window completely. 3.Without direct sunlight it will not work. 4. For tinted glasses it is ineffective. 5. Suction is very low for bigger cars 6. When mounted there is play. between edge of window and grove provided to the cooler.
Efficiency to use Efficient	Usable	Average ratings given by the variety of customers and users.
Error free in use Safe	Safety	1. The gap worries the user. 2. It is automatic it may start when not mounted. 3. There is a risk of theft of the car if it is left unattended.

		5. As electronics parts lie exactly below the solar panel, over a period of time it may get damaged.
Easy to use Friendly	User-friendly	1.Easy to operate. 2.No need of training or manual. 3.All parts are in single assembly.
Enjoyable in use Pleasurable	User Experience	1.Not up to the mark as in commercials. 2.Some parts can be detached so that gaps can be eliminated. 3.Anti-theft alarm system can be added.

4.9.6 Prioritization of variables

This is done based on the pairwise comparison method, as discussed in pilot study 1. The prioritization of design elements gives % weightage to each of the identified design elements. Generally, it is a tough job for MSMEs and designers to assign weightage to design elements and follow them. This will help them and save time in designing phase.

Table 4.20: Weightage and prioritized elements of Ergonomics and Pairwise comparisons

Ergonomics

Posture	Anthropometry	Reachability	Visibility	Direction	Glance	Force	Repetition	Duration	Safety	Effciency
A	A	C	D	E	A	A	A	I	J	K
	B	B,C	D	B	B	G	H	I	J	K
		C	C	C	C	G	C	C	J	K
			D	D	D	G	D	D	J	K
				E	F	G	H	I	J	K
					F	G	H	I	J	K
						G	G	I	J	K
							H	H	J	K
								I	J	I
									J	J
										K

Before pairwise comparison		After pairwise comparison		
	Parameters	Prioritized	Rank	% weightage
A	Posture	Safety	1	17.20%
B	Anthropometry	Efficiency, Reachability	2	13.70%
C	Reachability	Visibility, Force, Duration	3	10.32%
D	Visibility	Repetition, posture	4	6.88%
E	Direction	Anthropometry	5	5.16%
F	Glance	Direction	6	3.44%
G	Force	Glance	7	1.72%
H	Repetition			
I	Duration			
J	Safety			
K	Efficiency			
L	Ergonomic fit			

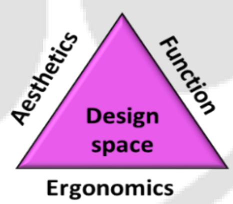


Table 4.21: Weightage and prioritized elements of Function and Pairwise comparisons

Function

	Need	Features	Value	Strength	Durability	Safety	Efficiency	Stability	Construction	User friendly	Cost	Ergonomic fit
	A	A	B	D	E	F	G	H	A	J	K	A
		B	B	B	E	F	G	B	B	J	K	B
			C	C	E	F	G	C	C	J	K	L
				D	E	F	G	D	D	J	K	D
					E	F	G	E	E	E	E	L
						F	F	G2	F,I	F,J	F,K	F
							G	G2	G	J	K	G,L
								H	H	J	K	L
									I	I,J	K	L
										J	J	L
											K	K,L
												L

Before pairwise comparison		After pairwise comparison		
	Parameters	Prioritized	Rank	% weightage
A	Need /purpose	Safety	1	14.20%
B	Features	Efficiency, User friendly, Cost	2	12.78%
C	Value	Durability, Ergonomic fit	3	9.94%
D	Strength	Features	4	8.52%
E	Durability	Strength	5	5.48%
F	Safety	Need, Value	6	4.26%
G	Efficiency	Stability	7	2.84%
H	Stability	Construction	8	1.42%
I	Construction			
J	User friendly/ease of use			
K	Cost			
L	Ergonomic fit			

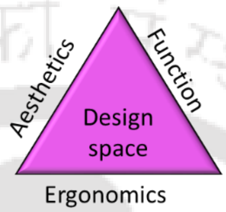
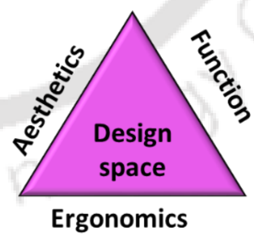


Table 4.22: Weightage and prioritized elements of Aesthetics and Pairwise comparisons

Aesthetics

	Unity	Symmetry	Balance	Rhythm	Color	Harmony	Emphasis	Visual	Proportion	Style
	A	A	A	A	E	A	A	H	A	J
		B	B	B	E	F	B	H	B	J
			C	C	E	C	C	H	C	C
				D	E	D	G	H	D	J
					E	E	E	H	E	J
						F	F	F	I	J
							G	H	I	J
								H	H	H
									I	J
										J

Before pairwise comparison		After pairwise comparison		
	Parameters	Prioritized	Rank	% weightage
A	Unity	Visual	1	18.16%
B	Symmetry	Style, Color	2	15.89%
C	Balance	Unity	3	13.62%
D	Rhythm	Balance	4	11.35%
E	Color	Symmetry	5	9.08%
F	Harmony	Harmony, Rhythm, Proportion	6	4.54%
G	Emphasis	Emphasis	7	2.27%
H	Visual			
I	Proportion			
J	Style			



After the prioritization, next step would be developing the concepts of the product which is shown below, followed with concept selection matrix and rankings.

4.9.7 Concept Generated to improve the product –Auto vent cooler for car

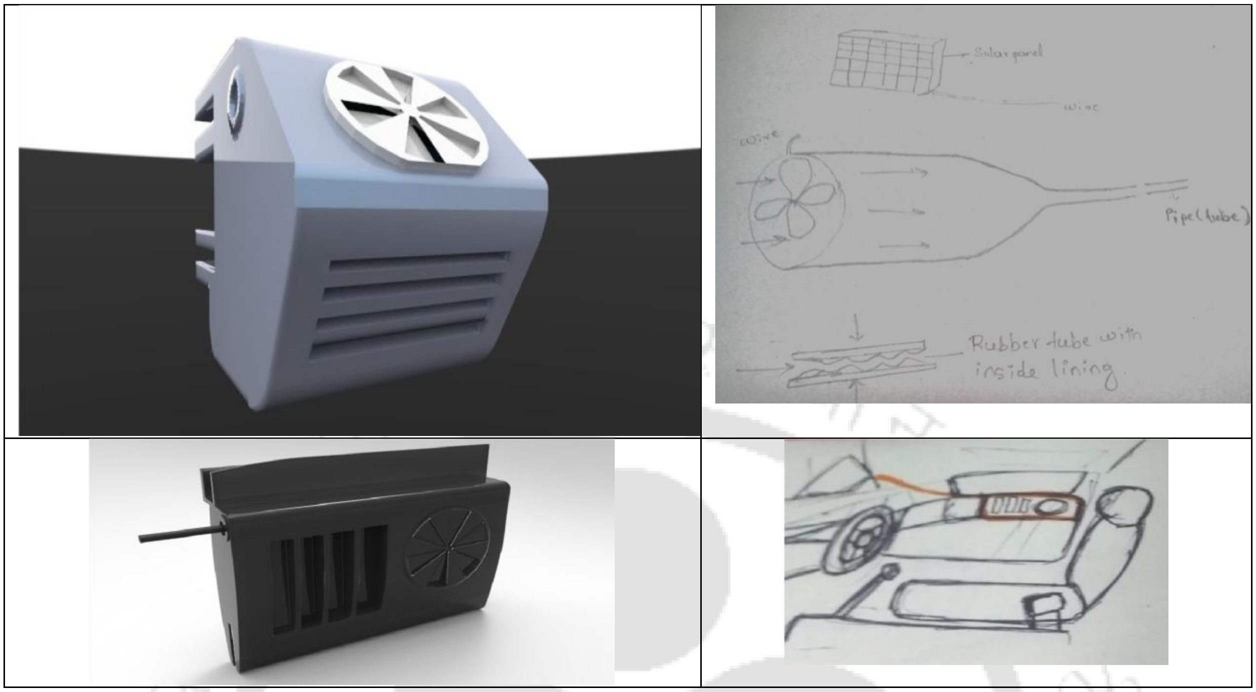
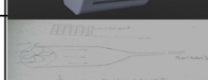


Figure 4.24: Concepts generated during the improvement of product

Table 4.23: Shows the ranking of the concepts generated

		Design Methods Applied	Degree of newness		Design Criteria (strong=9; medium=3; weak=1)								Sheer Innovation Prospect	Rank
				Criterion weightage	9	9	9	9	9	9	3	3		
Problem 1: Solar powered auto vent cooler					Low Cost	Light Weight	Efficiency	Functionality	Good ergonomics	Ease of use	Maintenance	Less process time		
Case 1														
Design1		Brain storming	3		3	9	9	9	3	9	3	9	414*3	3
Design 2		SCAMPER	3		9	3	9	9	9	9	9	3	432*3	2
Design 3		SCAMPER, linkograph	1		9	9	3	9	9	3	9	3	927*3	1

The observation from the Table 4.23 indicates that design 3 has a higher ranking and is selected from the generated concepts.

Based on the results of pilot tests, a design audit was carried out on seven products. The usability testing gives the user perception which will help in redesigning of the product. The best concept selection is based on the concept selection matrix. Prioritization of design elements will act as template for designers and MSMEs, here we are integrating the frame work in a reverse way for existing product being analyzed.

For both the products the proposed frame work of innovation gives consistent results and the frame work holds good and is validated. Using linkograph in the proposed frame work enables calculating relative innovation index. This will be discussed in chapter 5.

Summary of chapter 4: This chapter presents development of innovation frame work and their basis. Followed with experimental methodology as pilot testing of 2 products. Identifying design elements, influencing innovation in product design for developing fractal triangle of innovation framework for concept selection matrix and prioritization of design elements has been discussed. Product analysis steps, design audit has been described along with the pilot study. Detailed design audit has been carried out on identified category of products in the next chapter as main experiments.

Chapter 5

5. Consolidation of the Frame work for Innovation and Validation using Design Cases

Abstract: In this chapter, the innovation frame work proposed and pilot tested in earlier Chapter 4 is developed further and validated by using seven product cases for analysis. The innovation frame work is found to be useful. This chapter deals with developmental procedures adopted to formulate an innovation index, which contributes to identifying the gaps in design procedures of products, and help in summating the areas of improvement to enhance the utilitarian perspective from the, usability point of view. In continuation of the discussion in previous chapter 4, the process of developing linkographs has been further elaborated in this chapter to highlight the central thought behind the proposed frame work.

5.1 Introduction

In this chapter, we are presenting the case studies undertaken as part of research experiments. A total of seven case studies have been discussed. Several products which are archetypes in either material, manufacturing process, operations, usability, have been visually analyzed.

The flow of the study is as follows, formulation of fish bone diagram followed by value engineering, usability testing and engineering analysis. The study undertaken would help in identifying the existing gaps in the design procedures with respect to material, manufacturing process, operations and usability. The outcomes of the experimental study would help in conceptualizing the improvements needed by using the defined conceptual frame work for study.

Graph theory based 'Linkographs' technique adopted will aid in deriving the innovation index and would help in generating deeper insights into idea generation, idea screening, concept development and prototype development. The adopted method would unfold the design process in systematic design moves, i.e. innovation incorporated in the design phase by designers are quantified and the process is as shown in Fig. 5.1. The research work undertaken would lead to measuring innovation which in turn can become an index of comparison between a given set of similar products. Further areas/parts/components within the product can be identified or pinpointed which have potential for more innovation.

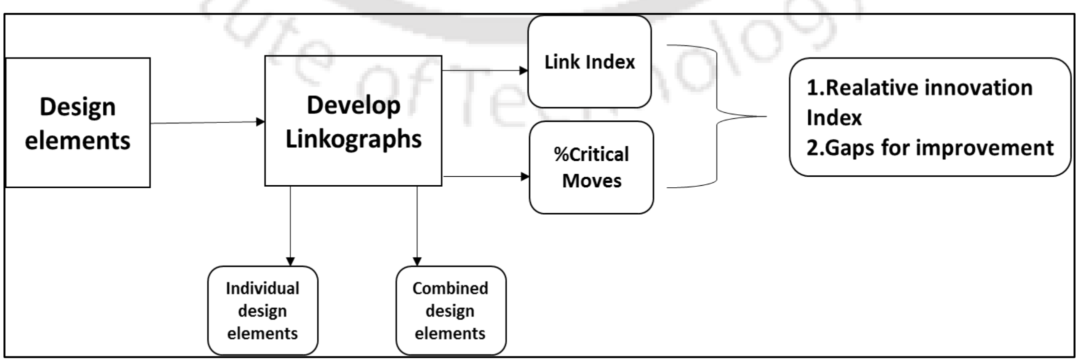


Figure 5.1: Linkograph an overview along with design elements (Author generated)

5.1.1 Why an innovation metric?

To compare any engineering improvement carried out is easier than comparing utility improvements and subjective attributes of a product. However, Innovation is a sum total value when seen by the user. It enables the incorporation and discussion as well as pinpoint possibilities of innovation. To achieve this there is a need to use a unifying index. This will aid the MSMEs in understanding their present level of innovation beyond engineering attributes such as at organizational, process and product levels. In addition, one needs to be able to systematically document where MSMEs need to concentrate/focus upon improving, given a product and limited resources. Other reasons are highlighted in the following section.

- To benefit from a tailor-made technique to identify and improve the gaps/areas to achieve innovation in their practices and products as well. With reference to the Indian MSMEs, it highlights the lacunae in the Government policies or to promote the innovative techniques through improvising the policies.
- It benefits in identifying the exact improvement locations/spots in a product to aid innovation.
- It can predict the next level/versions/generations of products, which will aid the MSMEs to be competitive, increase their creativity and innovation leading to higher productivity and profits.
- As an index it gives the relative innovation level for the given set of products of the same family.
- Such practices of indexing and documenting innovation activity, will hopefully bring the culture of innovation into their organization.

The need of innovation measurement has led to the study of currently available methods and models, their capabilities, applicability and ease of use.

On similar lines of pilot study presented in previous chapter 4 we proceed to conducting the design audit on the selected products and method represented by Fig. 5.2. This has been reproduced from chapter 3, Fig. 3.3 for ease of reference.

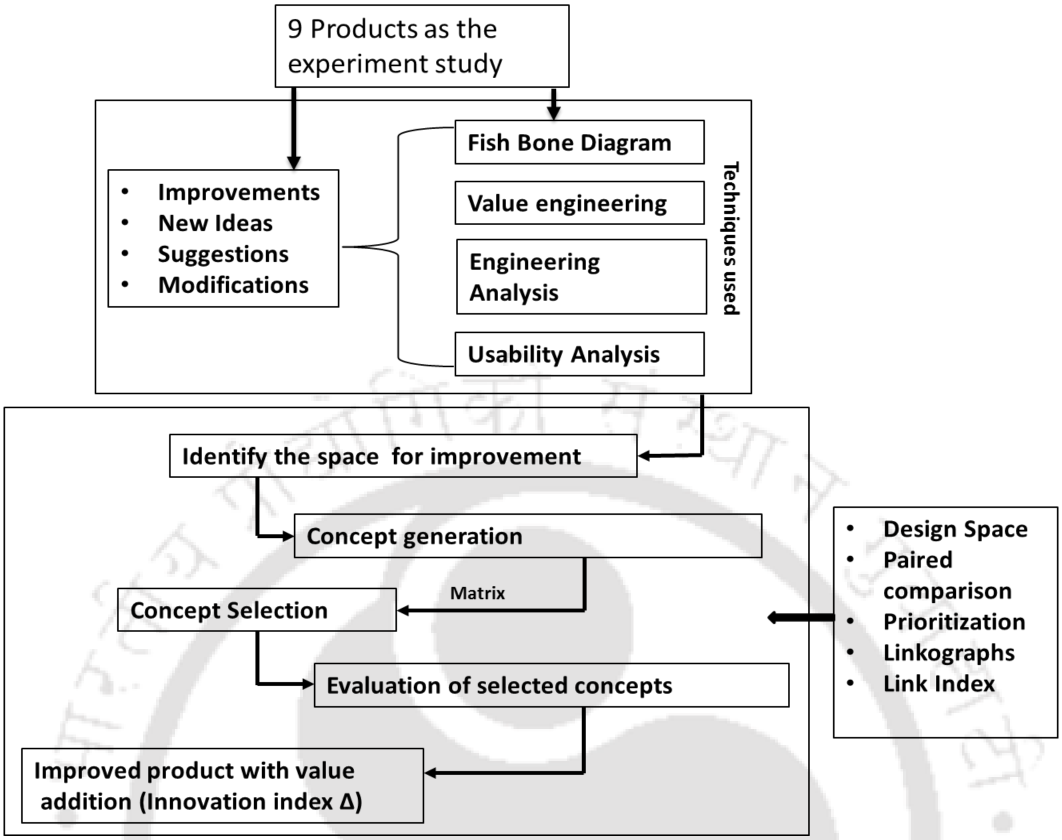


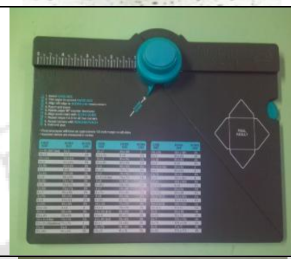
Figure 5.2: The method followed for the product analysis

5.2 Experimental Analysis: Case studies:

In this research nine (9) products have been analyzed. In which four (4) case studies i.e., 1. Bottle openers 2. Umbrellas, 3. Envelope makers, 4. Computing devices are dealt in detail with Technical analysis, Design audit and Generation of linkographs. Another three (3) case studies i.e., 5. Blenders, 6. Iron, 7. Garment Steamer were subjected to linkograph generation in order to identify the relative innovation index. Remaining two case studies i.e., 8. Earwax Remover, 9. Solar powered auto vent cooler have been dealt in pilot study in chapter 4. Steps followed in all the studies were Fish bone diagram, Value engineering an analysis, Engineering analysis and Usability testing. The later stage includes the generation of linkographs. The list of products chosen for analysis are as follows:

Table 5.0: List of products chosen for the analysis

Name of the product	Image of the product	Notes
1. Bottle opener		Design Audit and Linkography analysis

2. Umbrellas		Design Audit and Linkography analysis
3. Envelope maker		Design Audit and Linkography analysis
4. Computing devices		Design Audit and Linkography analysis
5.Blenders		Linkography analysis
6. Iron		Linkography analysis
7.Garment Steamer		Linkography analysis
8.Earwax Remover		From Pilot test chapter 4, section 4.8.1. Design Audit

9. Solar powered auto vent cooler		From pilot test chapter 4, section 4.9. Design Audit

5.2.1 Case 1: Multipurpose Bottle Openers- 3 different types of openers labeled as Opener A, Opener B, Opener C

The multipurpose bottle opener's design performance quality is heavily dependent upon the users grip comfort, ease of operation and ability to make product usage (usability) uncomplicated in everyday tasks. We have considered three openers labeled as product A, B & C as shown in Fig. 5.3a. The fish bone diagram, usability audit, value engineering and engineering analysis are carried out to understand the products' composition, physical configuration, assembly, usage of materials and human factors. Fig. 5.3a shows the different types of openers selected for the study.

		
Product A (122g)	**Product B (73 g)**	**Product C (65 g)**

Figure 5.3a: Different types of openers selected for the study

5.2.2 Problems observed in the Multipurpose Openers:

In India the size, diameters, designs of bottles are not standardized, which makes it difficult to design a product to be operated on bottles that follows the principle of "one size fits all" or "adjustable to size". Yet it is possible to come up with an innovative solution by design thinking and creative intervention. A multipurpose opener which works on the above principle across bottles sizes and types, and ensures that maximum value is delivered to the user, from a utilitarian perspective should theoretically be possible. To begin with variables of importance to the user have been identified first keeping UCD norms, by conducting usability audits and linkographs, which gives us insights into the properties of the users while using a jar/bottle opener. The focus of the study is to develop a product from a user's perspective.

Most of the available openers are made of metals and are designed for a particular function and size. At the same time there are expensive openers such as automatic can openers (Murphy), magnetic openers etc. The available openers are not designed ergonomically and there is no multi functionality in it. They deviate from the actual design space and design triangle. In countries like India, caps/seals are not standardized. In such cases, it becomes very difficult in using the available openers. Considering an ideal situation, a physically fit individual would have no problems whatsoever in opening the caps/seals. But sometimes it becomes troublesome to open the lids/caps, when we think of people with arthritis, MS disorder, elderly people. Further, tight lid caps add to the complexity in opening, like need for more strength, chance of slipping and hurting in case of non-grip handles and other exogenous variable like age, sex and physical fitness. Below images (Fig 5.3b) shows the problems observed and different type of solutions to open the jars.

Figure 5.3 b: Different types of Openers with the users

For the listed problems above, many numbers of solutions are already available. Multipurpose bottle opener would be a unanimous choice as it closely fits into our design space. If question is raised, what is an optimum solution for these kinds of problems? Although the defined opener in Fig. 5.3a, product A is considered as the best possible choice, it goes very well with our design triangle, considering the functionality, ergonomics, aesthetics, usability, utility etc.

Comparative analysis: Opener A versus other openers?

Based on the user's inputs (Templates were given and had the product review, Appendix B) the product under study was found to have good relation between the total curvature, length, with different diameters to open the lids of different sizes. The rubber gasket makes sure that it will not slip while turning. The lightweight and size makes it easier to use and it has good strength and durability. The other aspects like handles, which are ergonomically designed seem to be the natural extension of the hand. Functional aspects considering the exogenous variables makes the product designed the most suitable for use in any adverse condition and suit any user. The product is available in multiple colors, size and proportions which makes it handy and aesthetically a better product to use than other available products in the market.

Value engineering/analysis and engineering analysis was carried out to understand the product function-wise, component-wise, material-wise, cost-wise and analyzed for combining or deletion of the parts. It is done at product and component level. User study was conducted, wherein rating templates were created, for rating without bias. Prioritizing design elements was done based on the pairwise comparison method and user studies. To understand and calculate the value addition in terms of relative innovation index for the selected products linkographs were developed. As in our design theory (triangle) Product Proximity Factor zone (PPF) we posited that anything that comes very close to the human proximity like contact lenses extension of eyes, shoes etc. will lead to the innovation. When this product is compared with available openers in terms of its manufacturing costs, it is cheaper and offers more value to the users. We conducted the experiment exactly on the similar lines of pilot study and the steps followed are as shown in Fig. 5.2. The design audit has two parts viz. technical design and user centered design.

5.2.3. Main Features of Multipurpose Bottle Opener A

Table 5.1: Main features of the opener

Product Name	Multipurpose bottle cap opener
Size	9 x 2.5 x 0.7 inches
Colors available	Blue, Yellow, Red, Green
Users	Any ages people, Arthritic hands and aged individual
Function	Opening of bottle caps
Material	Highly durable plastic and soft rubber gasket
Cost	Rs. 299-/, 399/-
Weight	160 gm

How to use multipurpose bottle opener? Put the Multipurpose bottle opener on to the lid, tighten it with palm grip and hold the bottle with the other hand firmly, rotate/twist the opener.

What are the benefits of using multipurpose bottle opener?

- It effectively opens the lids/caps of bottles of any size without hurting.
- It is safe and quick to use, no risk involved.
- It is light weight and it can be carried anywhere, along with you.
- Easy to use, safe and fast, travel friendly, effectively opens almost all sizes bottles.

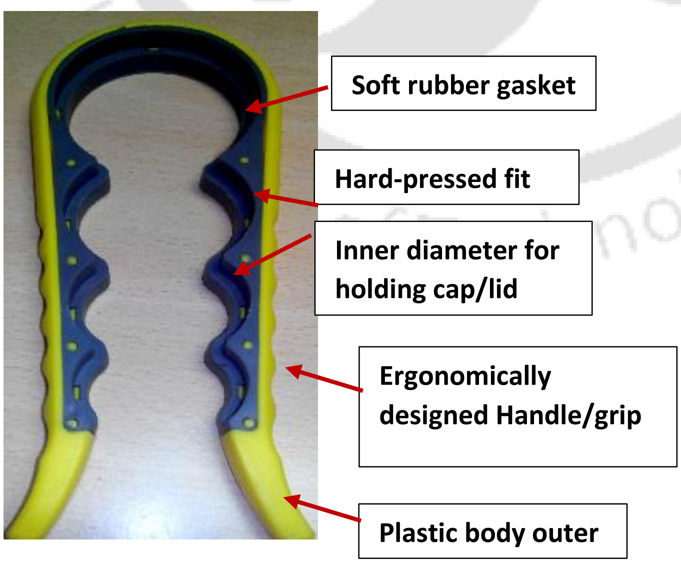


Figure 5.4: Multipurpose opener with its parts

5.2.4. Fish bone diagram of Multipurpose Bottle Opener A

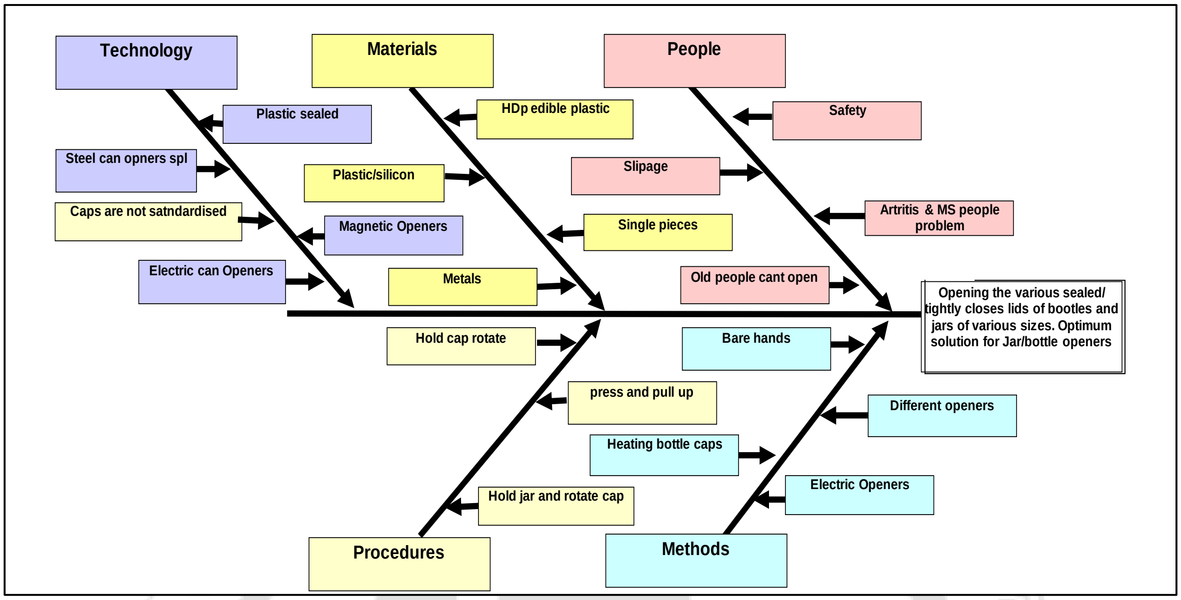


Figure 5.5: Fish bone diagram for Multipurpose Opener A

The understanding of the product right from the poor to good features and their functional roles are represented using the fish bone diagram as in Fig. 5.5.

The user and product task flow is explained with task flow diagram as shown in Fig. 5.6.

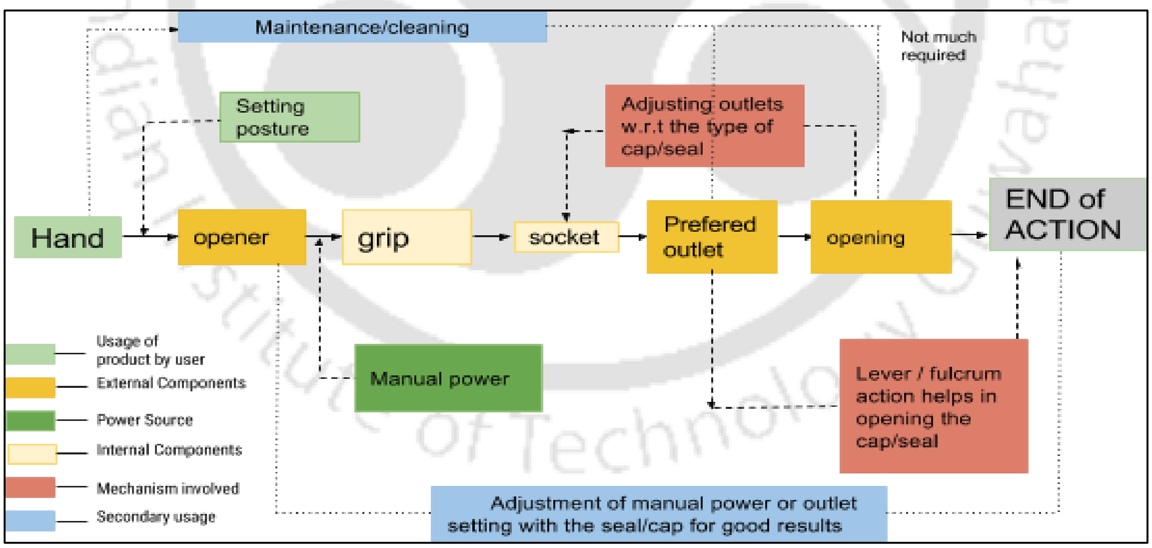


Figure 5.6: User-Product Task flow diagram of Multipurpose Opener A

5.2.5. Value engineering and value analysis of the product Multipurpose Bottle Opener

Value analysis is done in order to find cost per function per part. This clearly gives the redesigning part by combining functions. In this, there are only two parts so there is no need for redesigning with respect to cost as shown in Table 5.2. The improvements can be done by generating concepts discussed in the further section.

Table 5.2: Value engineering of Multipurpose Bottle Opener A

Sl No	No of Parts	Component	Function	Material	Importance to customer	Cost in Rs	%	Need of alteration and reason	Priority of redesign
1	1	Outer body	Provide the body for inside pressed silicon rim. Provide the grip for the User Verb: Hold Noun: Grip	Hard plastic	High	40	10	No	-
2	1	Inner body	-Acts as holder to caps/lids Verb: Hold, Noun: Support	Silicon	Medium	60	15	No	-

The total cost of the product is Rs. 399/- from online shopping sites. For cost estimation individual parts, prices are checked in websites and evaluated. For some parts, it is calculated based on material, process, etc. as shown in Table 5.2. To be a successful product, it should focus on the user, innovative, price and functional aspect. To prove the existing product performance one can redesign some of the parts based on the value analysis.

5.2.6. Engineering analysis or component manufacturing costs

Table 5.3: Engineering analysis of Multipurpose Bottle Opener A

Sl No	Component	Figures	Material	Process	Properties	Fixed costs in Rs.	Variable costs in Rs.	Volume	Total Unit Cost in Rs
1	Outer body		Hard plastic	Injection molding	Strength, durable, last longer is good	20	20	1	40
2	Inner body		Soft rubber	Injection molding	Strength, durable, last longer is good	38	22	1	60
3	Assembly		Plastic + silicon	Hard Pressed		25	23		48

Design Audit I Technical design Value Engineering, Fishbone diagram, Engineering analysis	**1**	Information required for this part of our proposed frame work has been constructed focusing on technical design, by the analysis in Table 5.3. on similar lines as mentioned in pilot study, (Chapter 4 section 4.7, Fig. 4.10). From value engineering inferences we map cost to function and get the priority for redesigning parts. Engineering analysis leads to exploring for material change, process change, cost of each parts etc. Fish bone diagram documents the role of each part in terms of performance which leads to a composite view of the overall improvements.

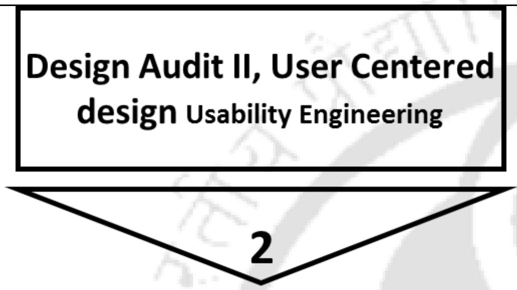
5.2.7. Usability audit of Multipurpose Bottle Opener A

Usability audit involves the 5 E usability testing. Usability is the ease of use and learnability of a human-made object such as a tool or device, that interacts with human Usability testing – a sub set of usability has been done in this thesis based on principles and definitions as in standards such as -9241, IEE 90, ISO 13407. 5 E principles are Effectiveness (Functional), Efficiency, Error free use, Easy to use, Enjoyable in use(Pleasurable).

Table 5.4: Usability audit of Multipurpose Opener A based on 5 E principles

Parameter	Details	Remarks/Problems
Product Identification	Multipurpose bottle Opener A	
User type Identification		Any one above the age of 10 can use it
Environment	Workspace Work surface	1. Homes 2. Kitchen
UE Principle 1 Effectiveness (Functional)	Features Limitation Consequences	1. Not 100% effective. More Effort is needed. 2. Difficulty in using as it slips while twisting. 3. Repeated use causes chipping of the material. 4. Bottle caps cannot be opened.
UE Principle 2 Efficiency	Usable	Average ratings were given by the variety of customers, referring to the online reviews and each product was examined for each of the usability principle by the researcher and observations drawn.
UE Principle 3 Error free use	Safety	1.If lids are tight then fear of slipping is a distinct possibility. 2. Small kids cannot use it properly.

UE principle 4 Easy to use	User-friendly	1. Easy to use, anyone can operate easily, even people suffering from arthritis. 2. No need of training or manual. 3. Made up of a single body.
UE Principle 5. Enjoyable in use (Pleasurable)	User Experience	Not up to the mark as in commercials. Variety of colors can be added, soft grips, attachment of can openers/bottle can be added.

	User centered design, of our proposed frame work has been constructed on similar lines of the pilot study, which will contribute towards understanding of the product in a better way from the user's perception (Chapter 4, section 4.6.4, Fig. 4.9). Here the usability audit has been carried out based on the 5 E principles. It makes the designer and MSMEs to think from user's point of view while they design any product. This test brings out problems faced by user while using the product. Overall usability, design helps in redesigning and improving the product.

We have generated design concepts that incorporate the results of the audit. The most appropriate of the concepts can be selected using our matrix framework for evaluating innovation criteria of a design process output during product conceptualization. By developing linkographs and utilizing the relationship shown below, it is possible to compare which one of the design concepts is innovative.

$$\text{Sheer innovation Prospect} = \left[\left(\Sigma \text{ Level of meeting design criterion by the concepts}\right) \times \text{Criterion Weights}\right] \times \text{Degree of newness}$$

………. Equation 3

5.2.8. Design improvements/Concepts generated during the study

On similar lines the Opener B and C are analyzed to identify the scope for improvements. The concepts that were generated are shown below.

Concept 1 This concept is inspired by combination of bottle opener and single size jar opener.

Concept 2 This concept focuses on increasing functionality by making squeezing/pressing action to open the cap easily. It works on the principle of wire cutters. In addition, the shape of the mouth can similarly help accommodate various sizes of caps. The mouth is then lined with ridges for better grip and functionality.

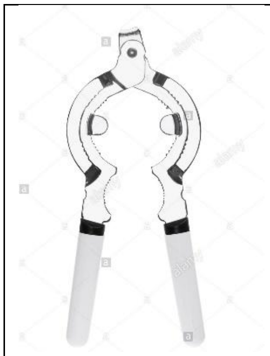


Figure 5.7: Concept 1


Figure 5.8: Concept 2

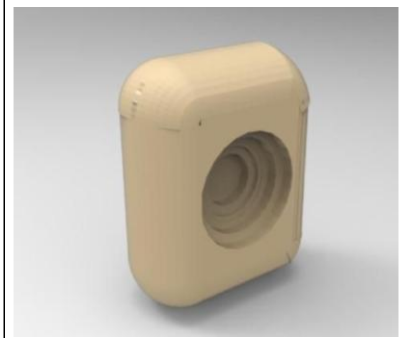
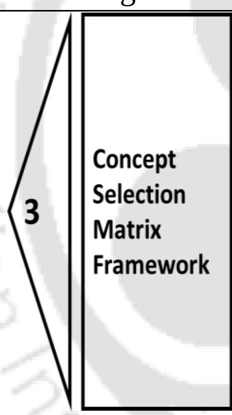


Figure 5.9: Concept 3

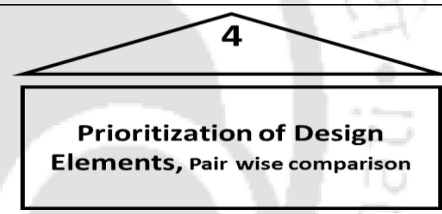
Concept 3 for Multipurpose bottle opener to suit more than one size.

This concept is inspired by the functioning of a sponge. It focuses on simplifying the process of applying pressure to open something with ease. The ridges are lined with rubber for better grip. It is compact and fits in the user's palm.

In next step, initial metricizing of the problem by developing an adjacency/dependency matrix, pairwise comparison weights and prioritized design element were conducted.



Concept selection matrix framework is simple and easy to use. It is based on technical design, usability and prioritization. One needs to consider all the above factors and start generating concepts. Our framework will be helpful in identifying the best concept based on ranking and is selected as the final design. (Chapter 4, section 4.5, Table 4.2)



Prioritization of design elements will help the designer and MSMEs to quickly understand and give weightage to the parameters that are important in achieving innovation, by saving time and works as template for such type of products. (Chapter 4, section 4.6.3, Fig. 4.8)

Table 5.5: Results of Concept selection matrix

		Design Methods Applied	Degree of newness		Design Criteria (strong=9; medium=3; weak=1)								Sheer Innovation Prospect	Rank
				Criterion weightage	9	9	9	9	9	9	3	3		
Problem 1: Multipurpose opener					Low Cost	Light Weight	Efficiency	Functionality	Good ergonomics	Ease of use	Maintenance	Less process time		
Case 1														
Design1		Brain storming	3		3	9	9	9	3	9	3	9	333*3	2
Design 2		SCAMPER	1		1	3	3	3	9	3	3	3	216*1	3
Design 3		SCAMPER, linkograph	3		1	9	9	3	9	3	3	9	342*3	1

In assigning the values in the Table 5.5, three designers/experts were involved in reviewing and assigning the values. In concept generation, individual designer used different design methods to generate concepts. In assigning the values to the degree of newness, a formal discussion followed with brainstorming session was done. Same method is followed for all case studies where ever the values were assigned.

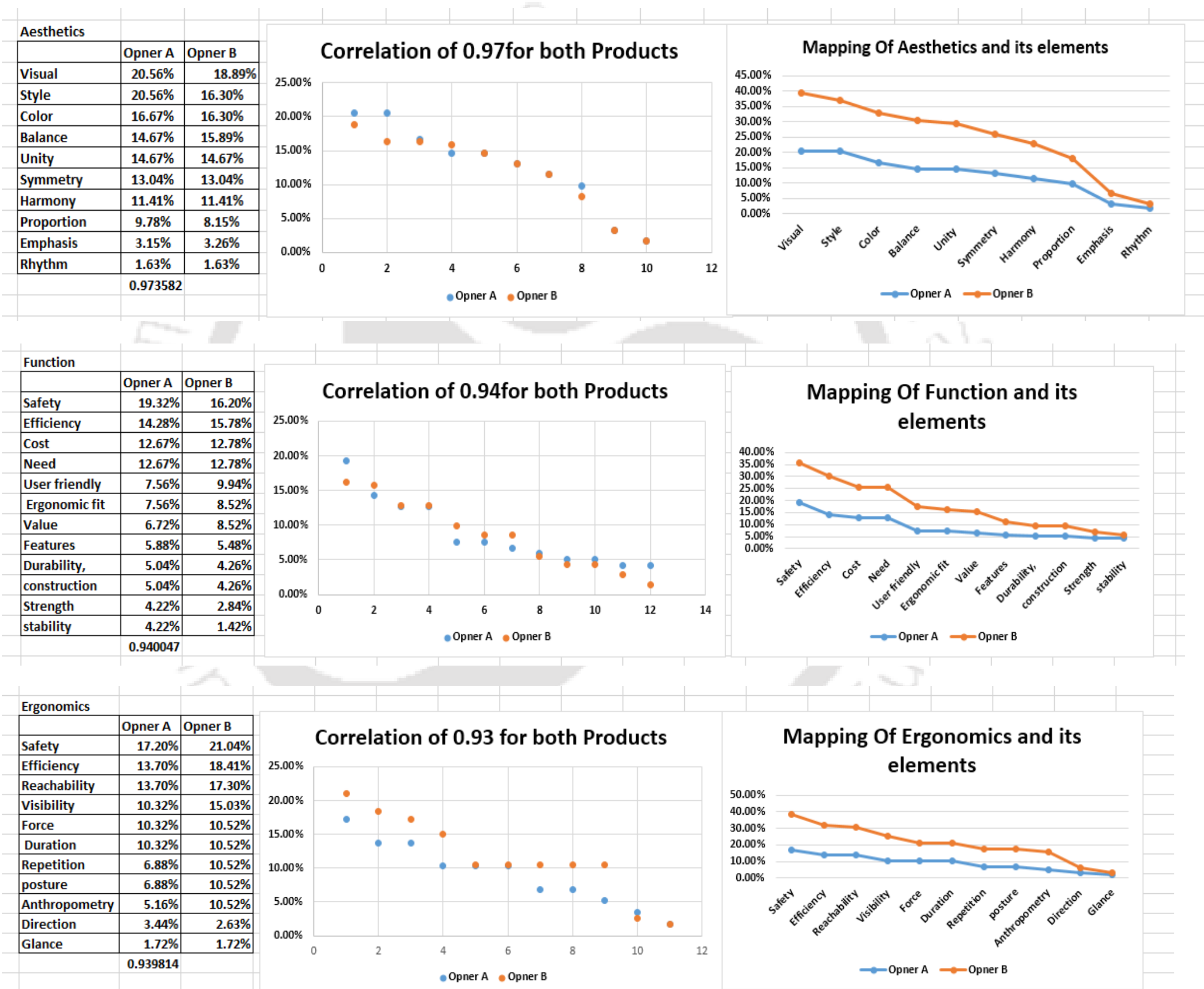
Sheer innovation potential is based/developed on the design methods, criterion (listed) weightage, design criteria, degree of newness etc. It is good for concept selection as the design criteria involved are simple and effective. Developed concept is better in terms of cost, light weight, function, ease of use, maintenance and process time, which are very few in comparison with fractal triangle of innovation. It gives the final ranking for concept selection.

Linkographs are built based on the design elements which influence in aiding innovation. Generated linkographs will give the exact spots of value addition. Relative innovation index is based on the link between the parameters and product. Hence it becomes easy for anyone to compare and identify the areas of improvement. Therefore, we require such type of metric for innovation index.

Some small enterprises will not be in a position to understand and calculate the sheer innovation potential (It requires time and skilled people with design knowledge). Linkography compares two products by plotting, one can observe the difference in terms of aesthetics, ergonomics, usability, function etc.

5.2.9 Prioritized design element's, correlation and regression analysis

A correlation and regression analysis was computed for both the openers A and B, to understand closely the innovation that has been incorporated between the two products. Those micro steps itself are value additions. Pearson product-moment correlation coefficient was established to assess the trends of design elements (prioritized) and their weights for both the products. There was a positive correlation between all the prioritized design elements r=0.97, n=10, p=2.06E-6 for aesthetics and its elements, r=0.93, n=11, p=1.7E-5 for ergonomics and its elements and for function and its elements r=0.94, n=12, p=5.5E-6.



Aesthetics

	Opner A	Opner B
Visual	20.56%	18.89%
Style	20.56%	16.30%
Color	16.67%	16.30%
Balance	14.67%	15.89%
Unity	14.67%	14.67%
Symmetry	13.04%	13.04%
Harmony	11.41%	11.41%
Proportion	9.78%	8.15%
Emphasis	3.15%	3.26%
Rhythm	1.63%	1.63%
	0.973582	

Function

	Opner A	Opner B
Safety	19.32%	16.20%
Efficiency	14.28%	15.78%
Cost	12.67%	12.78%
Need	12.67%	12.78%
User friendly	7.56%	9.94%
Ergonomic fit	7.56%	8.52%
Value	6.72%	8.52%
Features	5.88%	5.48%
Durability,	5.04%	4.26%
construction	5.04%	4.26%
Strength	4.22%	2.84%
stability	4.22%	1.42%
	0.940047	

Ergonomics

	Opner A	Opner B
Safety	17.20%	21.04%
Efficiency	13.70%	18.41%
Reachability	13.70%	17.30%
Visibility	10.32%	15.03%
Force	10.32%	10.52%
Duration	10.32%	10.52%
Repetition	6.88%	10.52%
posture	6.88%	10.52%
Anthropometry	5.16%	10.52%
Direction	3.44%	2.63%
Glance	1.72%	1.72%
	0.939814	

Figure 5.10: Aesthetics, Function and Ergonomics correlation and regression results and their trends

Inferences: Overall, there was a strong, positive correlation between prioritized design elements for both the products. These rankings and weights can be utilized precisely in designing phase by designers. The mapping of all the elements is carried and a similar trend was observed.

One of the main objective was to find the relative innovation index with the help of graph theory based linkography technique. Here we have plotted the linkographs individually and combined them based on novel fractal triangle of innovation.

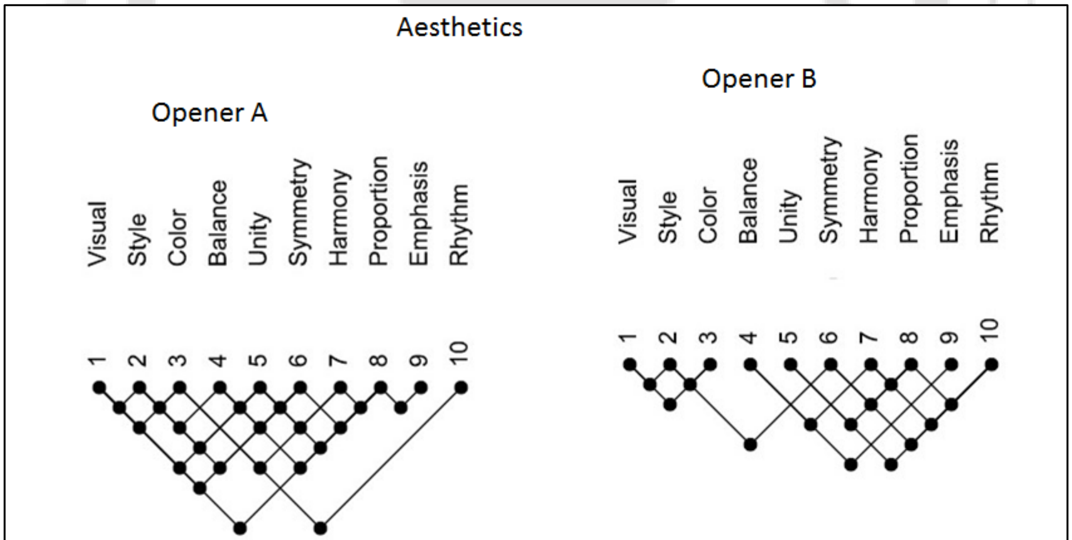
Innovation Measuring Index-Linkographs 5	Linkographs, unfolds the *qualitative* micro-steps into *quantitative* micro-steps i.e. Fig. 5.11 shows the index and links of both the openers. Based on the identified design elements (fractal triangle of innovation) linkographs are generated. It gives the link index nothing but innovation index both individually and combined. The detailed results are discussed in further section.

5.2.10. Linkograph generation

Detailed discussions of linkograph development for Openers under the three design space definers- Aesthetics, Ergonomics and Function.

Aesthetics

Observation: In Opener A, color, balance, unity and symmetry have lesser links in between the elements. In opener B visual, style, color, balance has very less links (Fig. 5.11**)**



	No of Moves N	Link Index LI	%CM 2	%CM3	%CM4	%CM5	%CM6
Product A	10	2		30	20	10	
Product B	10	1.4		10	10		

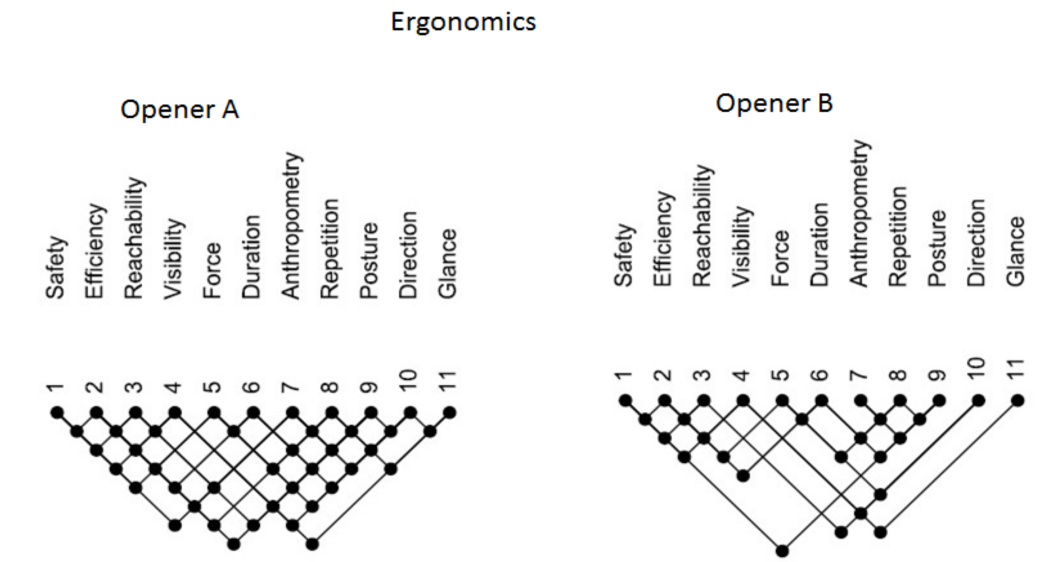
Figure 5.11: Linkographs for Opener A and B for aesthetics and its elements

Comparison indicates that the opener A has a Link index of 2 and 1.4 for the opener B, making B less innovative than A. To make opener B more innovative than A, we must concentrate more on the design elements which have lesser links in between them. If the connections are established which lead to a higher link index, the product is more innovative. If the link index is more than 2 in case of only elements of aesthetics, then the resulting product would be innovative by the amount of increase in the link index.

Even the critical moves signify the depth of analysis. We can observe the % CMs will signify the level of linking. The %CM5 is present in opener A and not in B, which also influence the relative innovation level aesthetic wise. A new product developed would be more focused on the harmony, proportion, emphasis and rhythm along with other design elements in case of opener A.

Based on the analysis, we conclude that aesthetics wise Opener A is found to be more innovative than Opener B.

Ergonomics

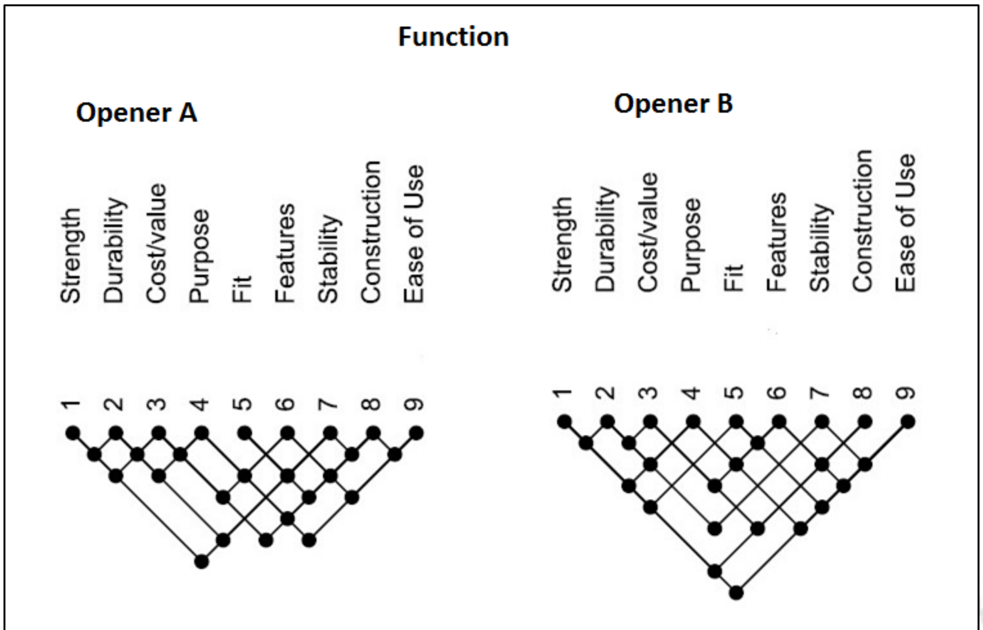


	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6
Product A	11	3		72.2	18.1	9.09	27.2
Product B	11	1.72		36.36	18.1		

Figure 5.12: Linkographs for Opener A and B for ergonomics and its elements

From the Fig. 5.12 we observe that for Opener A, the links are closely connected (even the physical product gives the feel of extension of the hand). On the contrary Opener B has less dense links therefore, it has more scope for improvement. Opener B can be improved by linking elements like reachability, visibility, force and glance. If the current product is modified and links established, it will generously increase the link index to higher than 3.0. Based on our analysis it is observed that Opener A has a link index 3 and Opener B has 1.72. Therefore, making the Opener A, more value added (innovative) than B. To conclude, w.r.t ergonomics the opener A has a higher relative innovation index.

Function



	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6
Product A	9	2.2		55.5	33.3		11.1
Product B	9	1.88		33.3		22.2	

Figure 5.13: Linkographs for Opener A and B for function and its elements

From the Fig. 5.13 Opener A is in close relation with strength, durability, cost, stability construction and ease of use. It is the same as Opener B, but B lacks in relating/linking the durability, fit, purpose and construction. These are the areas of improvement and one needs to concentrate more on this so as to innovate. When the moves and nodes are analyzed for function, the link index obtained are A=2.2 and B=1.88. Opener A is (0.32) better than B as value addition. With this analysis, we conclude that Opener A has more added value than B.

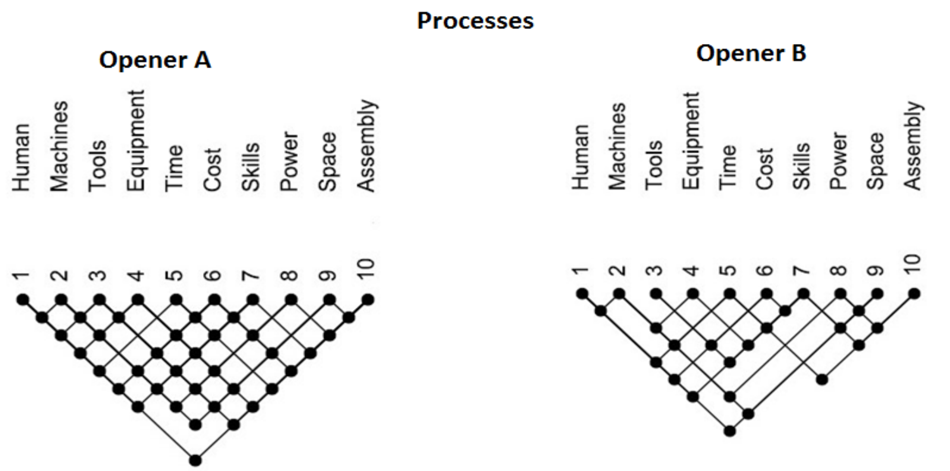
Similarly, Opener A is better than Opener B when process and its variables are plotted in linkograph shown in Fig. 5.14 and analyzed for the link index respectively. In case of operation and its variables it is observed that Opener B is lesser in value addition than Opener A, as shown in Fig. 5.15. When usability and its elements are compared, plotted and analyzed, the results leading to Opener A is better, as shown in Fig. 5.16 (Graphs are shown below).

On examining the results of individual design elements, Opener A has a higher link index than Opener B. Additionally %CM5, %CM6 and %CM7 are found to be present in Opener A making it form more number of links with design elements over the Opener B. Accordingly, we conclude that Opener A is more innovative in comparison with opener B.

In addition, linkographs were developed for the combined elements Aesthetics, Ergonomics and Function (AEF) which is nothing but the first fractal triangle of innovation and AEF being the 3 sides of the design space at 1st level. All the sub-parameters are plotted based on their relations. Opener A has a link index of 5.06 and B is 3.36 as shown in Fig. 5.17. Particularly Opener B has less interaction/link/relations with the design elements of all AEF. Thus, there is a lot of scope for improvement in the design of Opener B. If the question is raised, what would be the next innovation in the product? For Opener B to be more innovative than Opener A, it should have a link index higher than 5.06 for AEF. In this case Opener A is more innovative than Opener B.

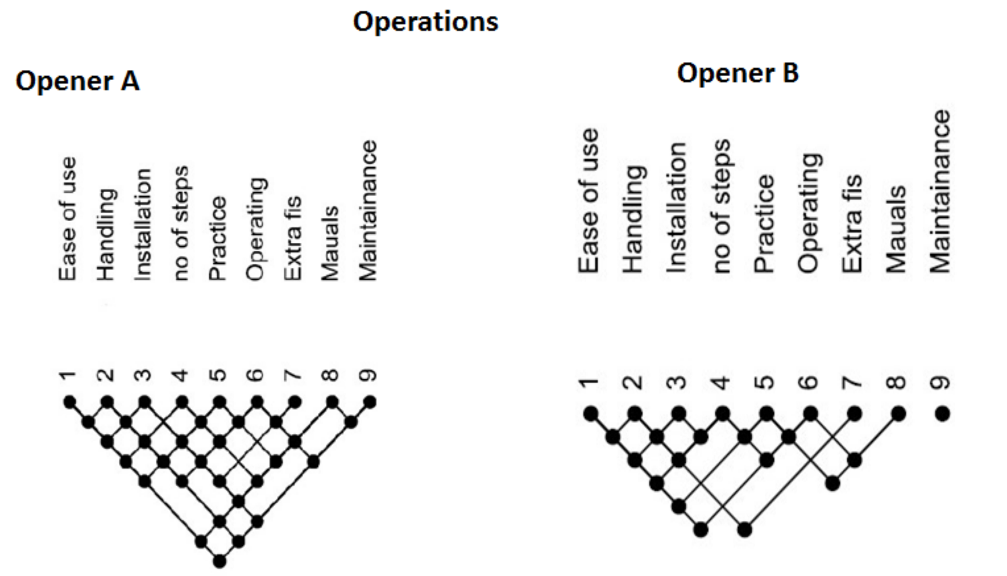
Similarly, the 2nd level would be Usability, Processes and Operations (UPO) in which the Opener A and Opener B have a link index of 7.96 and 3.88. From the results Opener A is better or innovative than the Opener B which is based on the UPO shown in Fig. 5.18.

5.2.11 Detailed linkographs of openers A and B



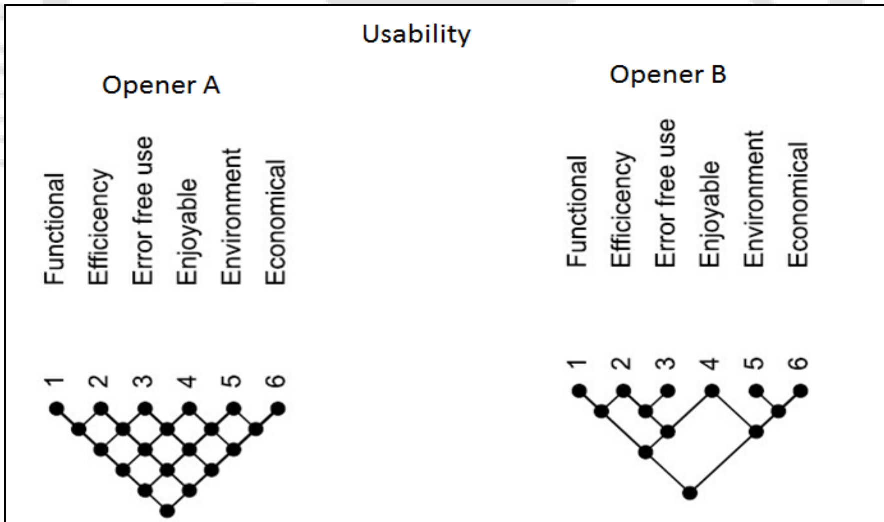
	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6
Product A	10	3.4		20	30	20	50
Product B	10	1.7		10	10	10	

Figure 5.14: Linkographs for Opener A and B for processes and its elements



	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6
Product A	10	3		30	50		40
Product B	10	1.7		40	10	10	

Figure 5.15: Linkographs for Opener A and B for operations and its elements



	No of Move s N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6
Product A	6	2.5		33.3	33.3	33.3	
Product B	6	1.16	33.3	33.3			

Figure 5.16: Linkographs for Opener A and B for usability and its elements

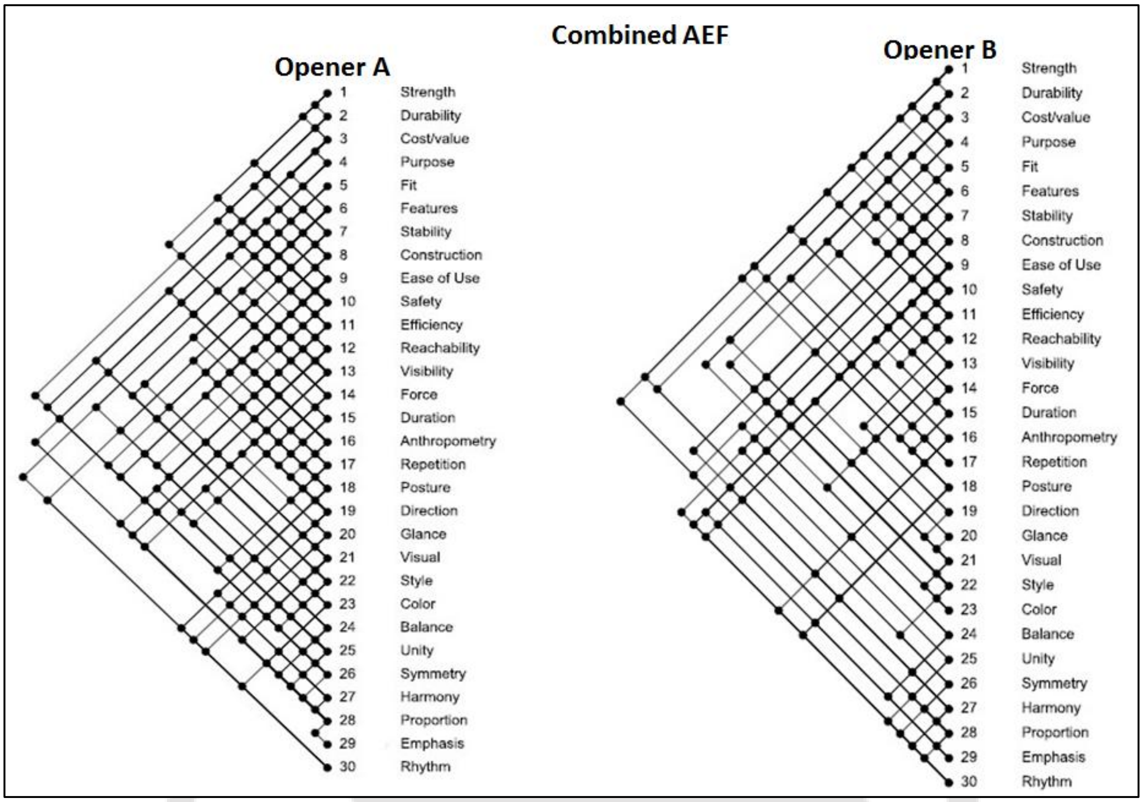


Figure 5.17: Linkographs for Opener A and B combined AEF and their elements

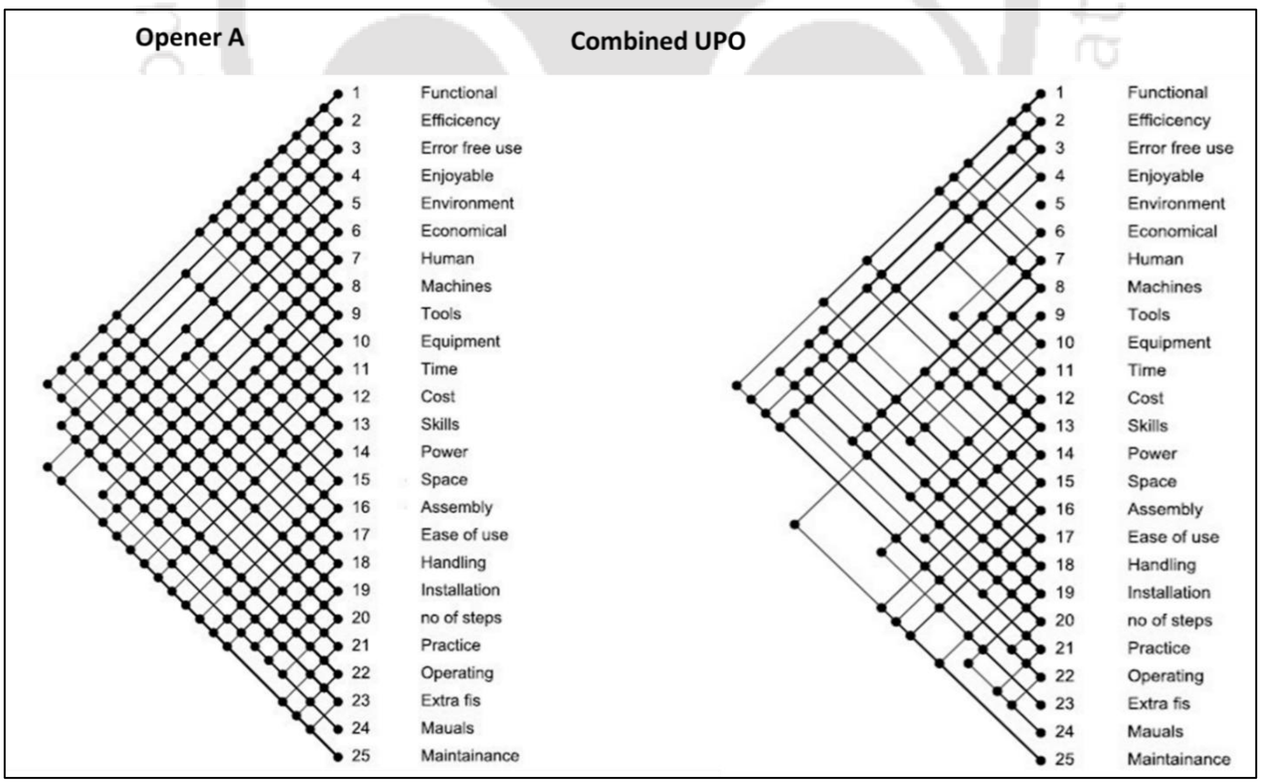


Figure 5.18: Linkographs for Opener A and B combined UPO and their elements

Table 5.6: Overall results of linkography plotted with Link index, critical moves

	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6	
Opener A	9	2.2		55.5	33.3		11.1	Function
Opener B	9	1.88		33.3		22.2		
Opener A	11	3		72.2	18.1	9.09	27.2	Ergonomics
Opener B	11	1.72		36.36	18.1			
Opener A	10	2		30	20	10		Aesthetics
Opener B	10	1.4		10	10			
Opener A	10	3		30	50		40	Operations
Opener B	10	1.7		40	10	10		
Opener A	10	3.4		20	30	20	50	Processes
Opener B	10	1.7		10	10	10		
Opener A	6	2.5		33.3	33.3	33.3		Usability
Opener B	6	1.16	33.3	33.3				

Combined AEF

Table 5.7: Combined overall results of Aesthetics, Ergonomics, Function

	No of Moves N	Link Index LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	%CM10	%CM11	% CM12	%CM 14
Opener A	30	5.06		23.3	23.3	23.3	26.6	16.6	6.66	6.66		10	
Opener B	30	3.36	40	16.6	30	16.6	13		3.3		3.3		3.3

Combined UPO

Table 5.8: Combined overall results of Usability, Processes, Operations

	No of Moves N	Link Index LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	%CM10	%CM11	% CM12	%CM13	%CM 14	%CM15+
Opener A	25	7.96	24	24	24			8	16	12	4				
Opener B	25	3.88				4	28	8	8	12		4	12	20	24

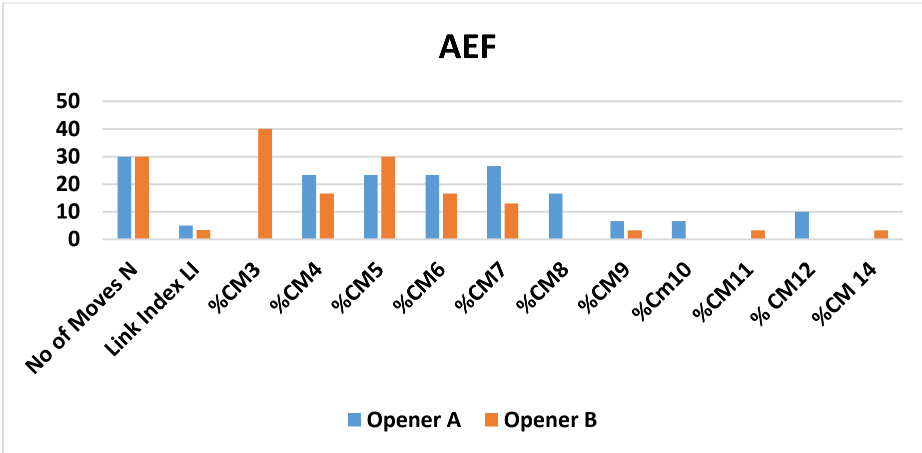


Figure 5.19: %CM for both openers in terms of AEF

Fig. 5.19 shows percentage (%) critical moves in terms of aesthetics, ergonomics and function for both the products. From Table 5.7 and above graph indicate the link index of both products along with % critical moves indicating the depth of the relations built and granularity of the analysis. On examination, we can infer that very few elements have a very deep relation in Opener B like %CM9, %CM11 and %CM14. But for Opener A, the number of elements in the relation are more therefore, making it more value added.

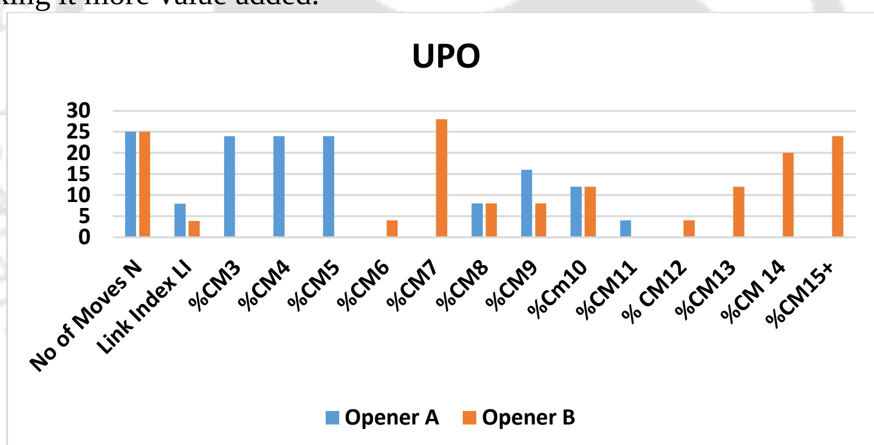


Figure 5.20: %CM for both openers in terms of UPO

Fig. 5.20 shows % critical moves in terms of usability, processes and operations for both the products. From Table 5.8 the graph indicates the link index of both products along with % critical moves indicating the depth of the relations built and granularity of the analysis.

Table 5.9: Consolidated results of link index of Opener A and B

	A	E	F	AEF	U	P	O	UPO
Opener A	2	3	2.2	5.06	2.5	3.4	3	7.96
Opener B	1.4	1.72	1.88	3.36	1.16	1.7	1.7	3.88

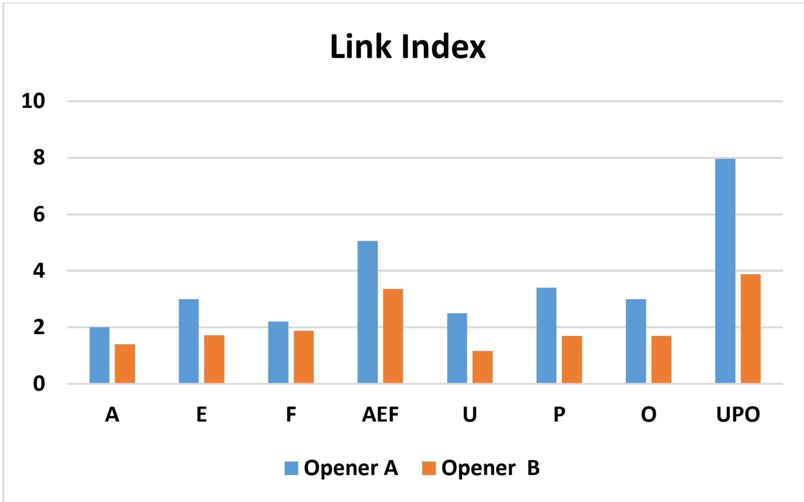


Figure 5.21: Link index for both openers in terms of UPO

The Fig. 5.21 shows that individual, combined link index of design elements for both the products. The Table 5.9 and the above graph clearly indicates that link index of Opener A is higher in all aspects, hence making it more value added than Opener B. This implies that higher the link index higher is the value added and that makes it more innovative. Further, the next opener should have higher link index than that of Opener A then only it will be innovative (Predicting the next opener). Further, we want to improve the existing opener, how we can do it? It can be improved by building up the relations that are missing in the linkographs. Therefore, we are framing a matrix called as a dependency matrix which is discussed in the next section.

5.2.12 Framing dependency matrix for new product or improvement of the existing product

Keeping in mind that the end goal is to enhance the exploration for dependency between the design elements with the product. It is suggested/endorsed that the product is broken down and analyzed as shown in the above sections as product analysis. From this we have developed the linkographs based on their relationships between the design elements. Further, we have developed a dependency matrix. "The matrix is a tool for systematic scanning of variables, making it to predict development in the product" [Goldenberg, 2002]. The matrix is derived from the Linkographs for the function and its elements, in case of opener A and B. The elements/variable of the matrix are selected after analyzing the linkographs and the elements having lesser inter connections or links will be taken for the framing of matrix.

From the matrix the elements having relation/dependency are rated 1 and rest as 0. For any product (here product is Opener A and B) if these 0's are converted to 1s i.e. the elements that do not having any relations/dependency amongst the design elements. This is used to try and establish the relations which leads to the improvement in the product along with the prediction of the next product. Based on the dependency matrix and identified design elements a 3X3 matrix is built in order to develop dependencies. This is shown with an example of multipurpose opener for function and its elements in Tables 5.10, 5.11 and 5.12 for ergonomics, function and aesthetics respectively.

Table 5.10: Dependency matrix from linkograph for Opener A, aesthetics

Product A Aesthetics	Visual	Style	Color	Balance	Unity	Symmetry	Harmony	proportion	Emphasis	Rhythm
Visual	0	1	1	0	1	1	0	1	0	0
Style		0	1	1	1	1	0	0	0	0
Color			0	0	0	0	1	0	0	1
Balance				0	1	1	0	1	0	0
Unity					0	1	1	1	0	0
Symmetry						0	0	1	0	0
Harmony							0	1	0	0
proportion								0	1	0
Emphasis									0	0
Rhythm										0

Table 5.11: Dependency matrix from linkograph for Opener A, ergonomics

Product A Ergonomics	Safety	Efficiency	Reachabilit y	Visibility	Force	Duration	Anthropom etry	Repetition	Posture	Direction	Glance
Safety	0	1	1	1	1	0	1	0	0	0	0
Efficiency		0	1	1	1	1	1	1	1	0	0
Reachability			0	1	0	0	1	0	1	0	0
Visibility				0	0	0	0	0	1	1	1
Force					0	0	0	1	1	1	0
Duration						0	0	1	1	1	0
Anthropometry							0	1	1	1	0
Repetition								0	1	1	1
Posture									0	1	0
Direction										0	1
Glance											0

Table 5.12: Dependency matrix from linkograph for Opener A, function

Product A Function	Strength	Durability	Cost	Purpose	Fit	Features	Stability	Constructio n	Ease of use
Strength	0	1	1	0	0	0	1	0	0
Durability		0	1	1	0	0	1	1	0
Cost			0	1	0	1	0	1	0
Purpose				0	0	1	0	1	1
Fit					0	0	1	1	1
Features						0	0	1	1
Stability							0	1	0
Construction								0	1
Ease of use									0

Openers case study, dependency matrix for Processes, Operations and Usability

Table 5.13: Dependency matrix from linkograph for Opener A, Usability

Product A Usability	Functional	Efficient	Error free use	Equipment	Environment	Economic
Functional	0	1	1	1	1	1
Efficient		0	1	1	1	1
Error free use			0	1	1	1
Enjoyable				0	1	1
Environment					0	1
Economic						0

Table 5.14: Dependency matrix from linkograph for Opener A, Operations

Product A Operations	Ease of use	Handling	Installation	No of Steps	Time	Operating	Power	Extra fits	Manuals	Maintenance
Ease of use	0	1	1	1	1	0	0	1	1	1
Handling		0	1	1	1	1	0	1	1	0
Installation			0	1	1	1	1	1	1	0
No of Steps				0	1	1	0	1	0	0
Time					0	1	0	1	0	1
Operating						0	1	1	1	1
Power							0	0	0	0
Extra fits								0	0	1
Manuals									0	0
Maintenance										0

Table 5.15: Dependency matrix from linkograph for Opener A, Processes

Product A Processes	Human	Machine	Tools	Equipment	Time	Cost	Skills	Power	Space	Assembly
Human	0	1	1	1	1	1	1	0	0	1
Machine		0	1	1	0	1	1	1	1	0
Tools			0	1	0	1	1	1	1	1
Equipment				0	0	1	1	1	1	1
Time					0	1	1	0	0	1
Cost						0	1	1	1	1
Skills							0	0	0	1
Power								0	0	1
Space									0	1
Assembly										0

From the linkographs, we develop a dependency matrix with design elements having relations of ‘1’ and non-related elements as ‘0’ (Which is the gap to establish the new relations). Now from the bigger matrix we identify the potential elements to build dependencies and create a sub matrix of size 3X3. This is then converted into a degenerated matrix to saturated matrix, i.e. all ‘0s’ to ‘1’. This can be done by establishing the dependencies amongst the identified design elements.

In Opener A, strength and purpose are shown in Table 5.12. It has no relation as the strength in the inner body is low and over the period of time it will wear out. Hence, that can be improved by changing the material (wear resistant and stiffer) which will solve the purpose. Accordingly, we are building the dependencies.

Similarly, strength and ease of use (represented by Table 5.12) can be maximized by optimizing the material. Here, the outer body is hard plastic, on which the hand grips are directly pressed. We could replace this with a soft grip that will make it easier to handle. It will also increase the usability and ergonomic parameters.

On the same lines as durability and ease of use, by the selecting the proper material (softer grip), we are making it more durable. This results in better ease of use for a longer period. The cost of the product is higher when the ease of use is considered. This can be optimized by changing the manufacturing process and using alternative materials of the same quality at cheaper cost.

After analyzing (prioritizing + product analysis + linkographs) dependency matrix and identifying the gaps of improvement, a 3X3 degenerated matrix has been converted to saturated matrix as shown in Fig. 5.22. If this is resubstituted in the linkograph, it will increase the number of nodes in the linkograph. This in turn increases the link index and % CMs leading towards product innovation. This happens to be an individual design element level. If we can build the relations in combinations, we can have many more relations in turn leading to higher number of connections leading to higher innovation index. If these matrices are substituted in the linkograph after forming relation in the identified matrix, it would lead to a higher number of links and conclusively increase the link index, which is nothing but the relative innovation index as seen in Table 5.16.

In the similar way, all the matrices can be framed and new relation can be established for aesthetics, ergonomics, usability, operations and processes. So the outcome will be well interconnected in the linkograph and also increase the level of relative innovation in product during the product design stage.

Product A Function	Strength	Durability	Cost	Purpose	Ease of use
Strength		1	1	0	0
Durability			1	1	0
Cost				1	0
Purpose					1
Ease of use					

0	1	1	0	0
1	0	1	1	0
1	1	0	1	0
0	1	1	0	1
0	0	0	1	0

After establishing the relations amongst these elements our new saturated matrix would be

Product A Function	Strength	Durability	Cost	Purpose	Ease of use
Strength		1	1	1	1
Durability			1	1	1
Cost				1	1
Purpose					1
Ease of use					

0	1	1	1	1
1	0	1	1	1
1	1	0	1	1
0		1	0	1
0	0	0	1	0

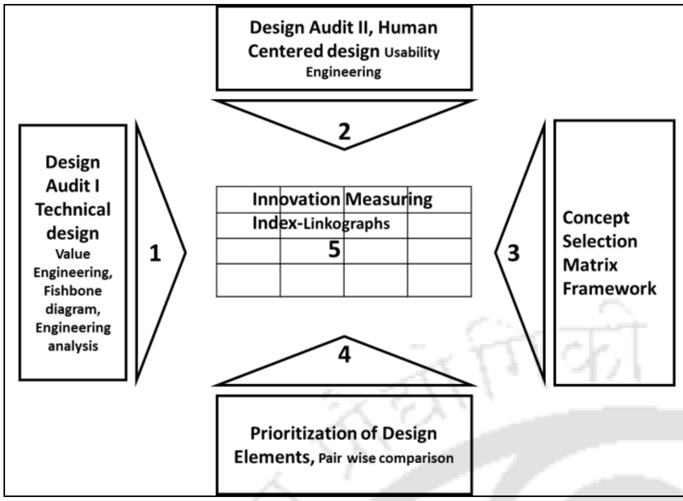
Figure 5.22: Developed dependency matrix for further building the relations

5.2.13. The results of the degenerated and saturated matrix after re-substituting in the linkograph

After building the relations, resubstitute and develop the linkograph, and measure the link index. This is compared with results of before and after as shown below in Table 5.16.

Table 5.16: After building the relations improved link index

	Before degenerated matrix							After saturated matrix						
	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6
Product A	9	2.2		55.5	33.3		11.1	9	2.55		55.5	33.3		11.1
Product B	9	1.88		33.3		22.2		9	1.88		33.3		22.2	

	Thus, stepwise we have constructed the proposed frame work using Opener A and B as products, for improvement and identifying the relative innovation index. With the help of linkograph one can directly spot the innovation spots, improvement areas in terms of design elements. One can predict the next level of product in that family of set of products for future.

5.3 Case Study 2, Product 2

Umbrellas- 3 types of umbrellas and raincoat as, U1, U2, U3 and R1 are selected for the study

5.3.1 Overview of Rain Protection Devices under study

A detailed user survey, with three (3) varieties of rain protection devices- four numbers of umbrellas and one raincoat, was carried out to do a product analysis, and identify the variables of importance to users as per their need and requirement. The study undertaken will help us in identifying the product features which consumers value in the product and rate them as per their importance from a utilitarian perspective. Alternatively, it may lead us to an entirely new type of product without disturbing the functionality.

 **Umbrella A (U1)**	   **Rain coat, R1** **Umbrella B &C (U2)**
 **Umbrella D (U3)**	Total 4 umbrellas are used as Product UA, UB, UC, UD Umbrella costs are in Rs. A:320/-, B&C:299/-, D:250/- Rain coat cost 600/- **Figure 5.23: Different umbrellas are considered for the experiments**

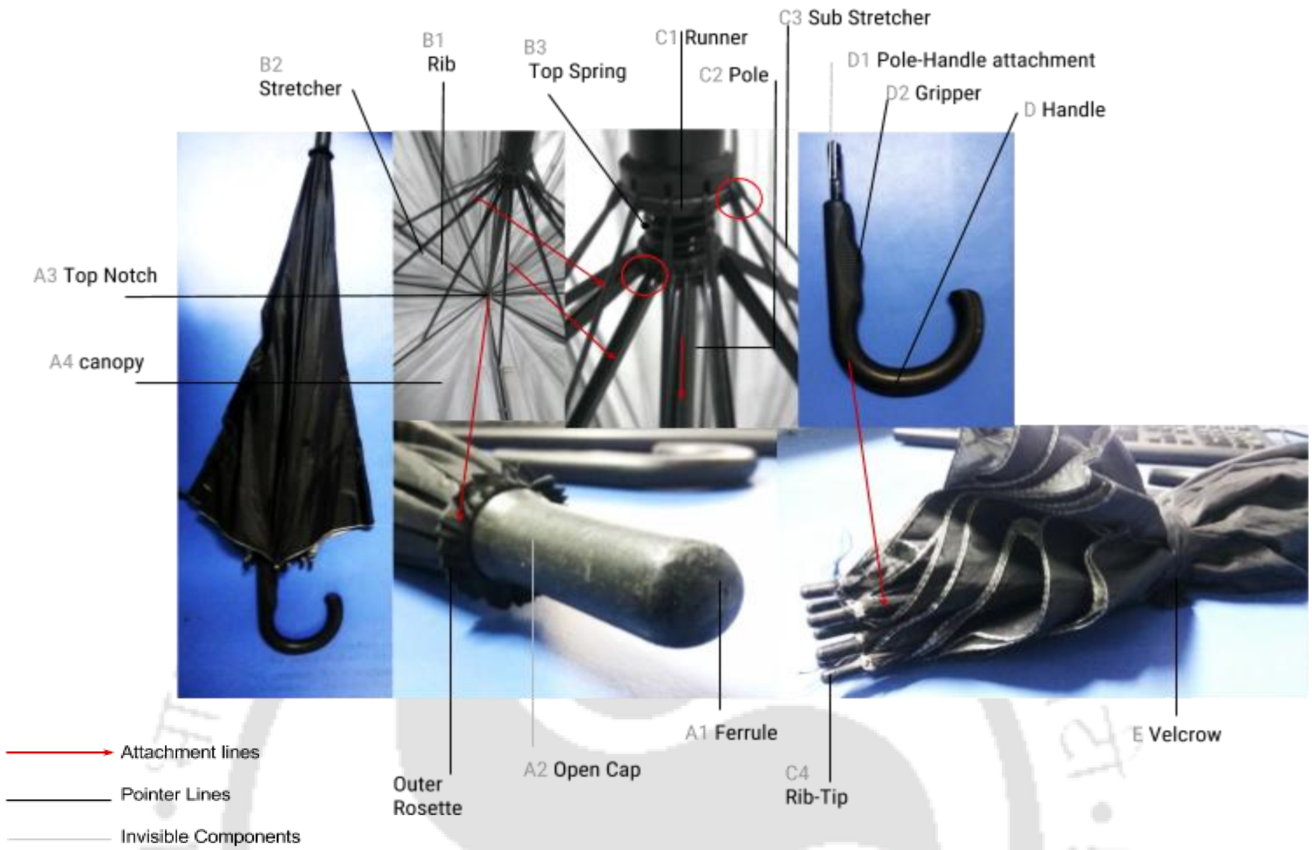


Figure 5.24(a): Umbrellas with all parts as part of reverse engineering

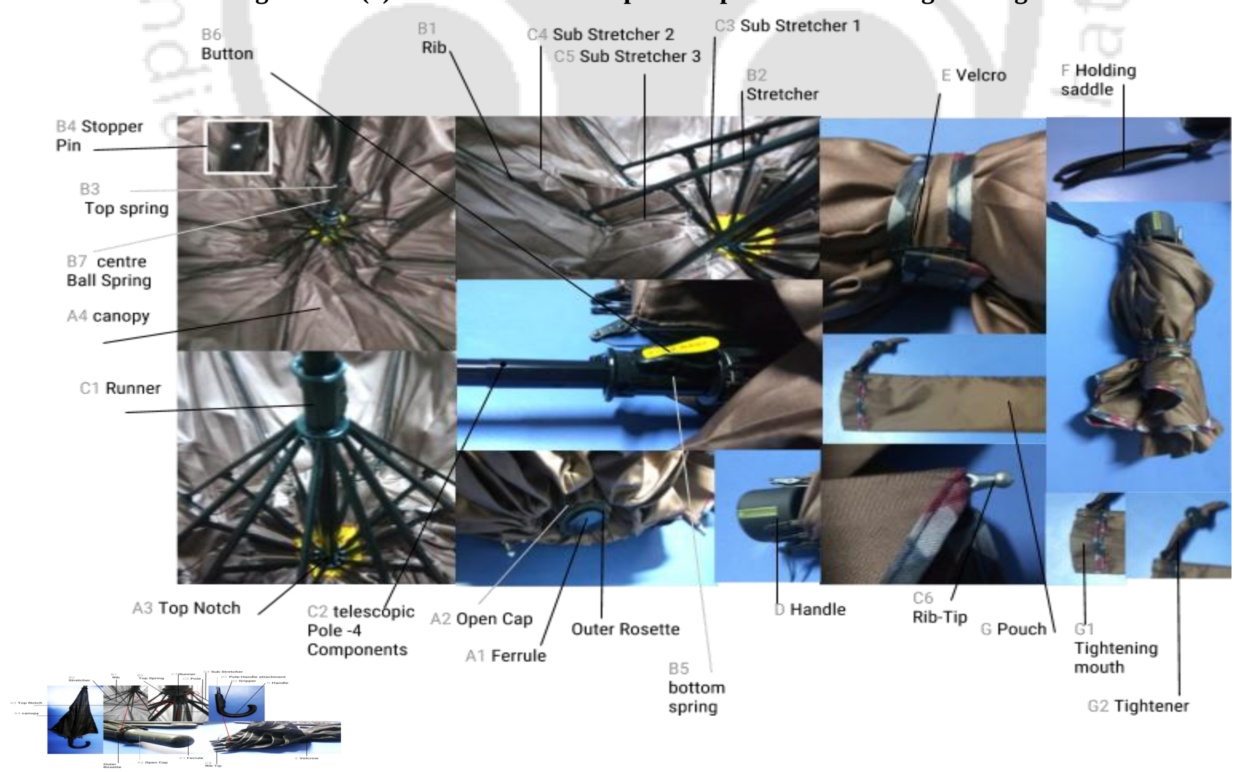


Figure 5.24(b): Umbrellas with all parts as part of reverse engineering

5.3.2. Fish bone diagram of Umbrella:

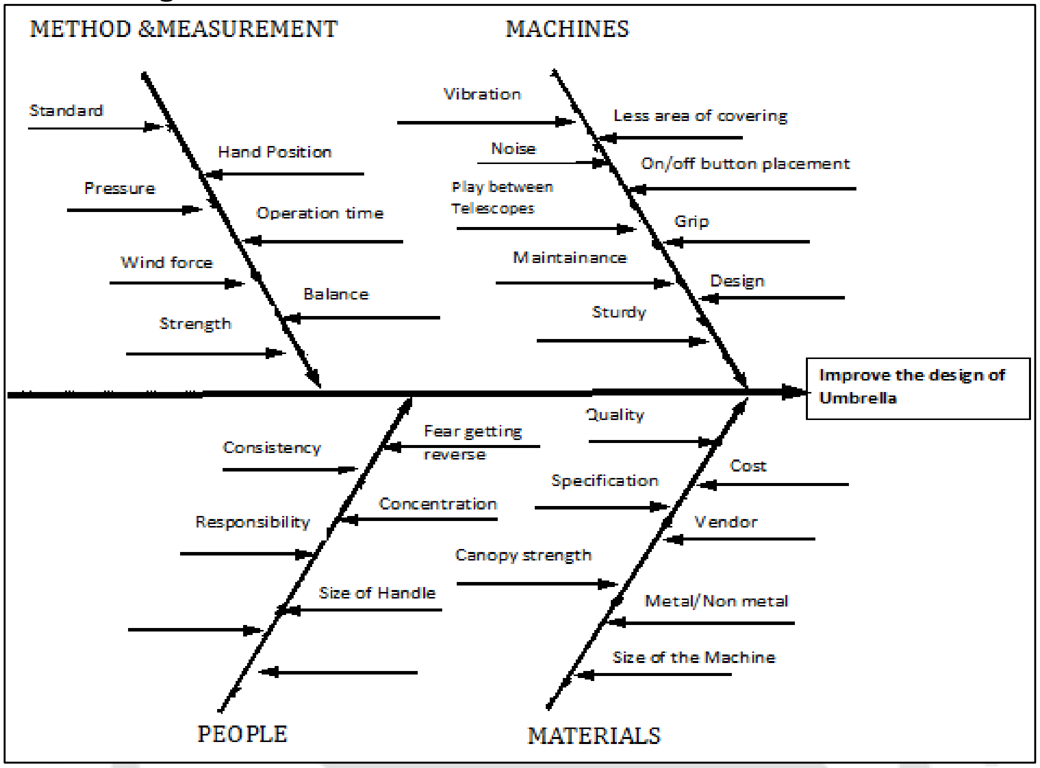


Figure 5.25: Fish bone diagram of Umbrella

The problems in umbrellas and all the characteristics can be identified with the help of a fish bone diagram as shown in Fig. 5.25

5.3.3. For value engineering we have considered Umbrella B & C as having cost of Rs. 299/-

Total disassembly of an umbrella can lead to the identification of the different parts, components, sub assembly, quantity and assembly. Estimation and value per function are shown in Table 5.17.

Table 5.17: The value engineering and its components of Umbrella B and C

Sl. N o.	No of Parts	Component	Function	Noun/ Verb	Importanc e to user	Cost in Rs	%	Need of alteration and reason	Priority of redesign
1	1	Cap	-It holds the canopy and the tube assembly. -Gives aesthetic looks -	Hold/ Support	-Low - Medium -	3	1.00	No	
2	1	Screw	-Attaches cap with canopy	Hold/ Support	Low	2	0.66	no	6

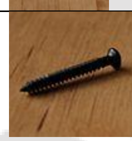
3	1	Cover	-When folded to store umbrella -When wet also it can be stored.	Hold/ Store/	-High -High	15	5.01	Yes	3
4	1	Handle/Grip	-To hold the umbrella. -Gives proper seating to the telescopic shaft -housing for the button	Grip/ Hold	-High -Low -Medium	30	10.03	Yes	5
5	1	Thread	-Attached to handle acts as holder -User can hold in his wrist while using/carrying -To hang on walls at home	Hang/ Store	-Medium	1	.33	May be	2
6	1	Canopy	-Acts as retracting roof -All spoke assembly get connects here -It gives the protection against rain, sunlight -Deflects rainfall		-Medium	75	25.08	May be	1
7	1	Plastic skirt	-Prevents rain fall near the cap and canopy assembly -Acts as stopper between two parts		Low	.50	.16	No	8

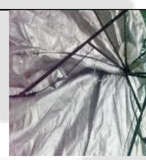
8a	1	Spoke assembly	-Provides the structure to umbrella -Acts as skeleton to body of umbrella		Medium	40	13.37	Yes,	4
8b		Plastic/ Steel cap	-Sits on tip of spoke which is in connection with canopy -Holds all spokes with canopy		-Medium	20	6.68	May be	
8c		Wire	-Prevents the spoke assembly from bending -Supporting element	Hold/ Support	-Low	10	3.34	No	
8d		Links	-Protract Canopy -Supports spoke assembly		-Low	15	5.04	Yes	
8e		Connecting link	Connects spoke sub assembly to steel/plastic cap connected to the canopy		-Low	5	1.67	Yes Redesign	
9		Concentric tube	Enables Spoke to extend for operation		-Low	13	4.34	No	
10		Shaft Assembly	Extends the umbrella for usage -Acts as backbone/Main support -Telescope shafts make umbrella compact		-Medium	40	13.37	No	

11		Concentric tube holder	Holds concentric tubes in tact			10	3.34		
12		Shaft Spring	-Locks when it opened -Ensures after opening does not come back			20	6.68		

5.3.4. Engineering analysis of Umbrella B & C:
In order to understand materials, processes to manufacture and cost are calculated in engineering analysis as shown in Table 5.18.

Table 5.18: Engineering analysis of Umbrella B and C

Sl. No.	Parts	Weight/ Dimensions	Figures	Material	Process	Fixed costs	Variable costs	Volume	Total Unit Cost in Rs.
1	Cap	2 gm		Plastic	Injection Molding	1.5	1.5	1	3
2	Screw	5 gm		Steel	Forming	1	1	1	2
3	Cover	10 gm		Polyester	Hand stitched	3	12	1	15
4	Handle/Grip	<50 gm		Plastic / Wooden/ aluminum	Injection molding	4	26	1	30
5	Thread	2 gm		Polyester	Threaded	.5	.5	1	1

6	Canopy	45 gm		Polyester	Hand stitched	5	70	1	75
7	Plastic skirt	<1 gm		Plastic	Cut			1	.50
8	Spoke assembly	20 gm		Aluminum	Pressing/ Stamping	10	30	8	40
	Plastic/ Steel cap	1 gm		Plastic / Steel	Casted/Injection Molding	5	15	8	20
	Wire	<1 gm		Aluminum	Shaping			8	10
	Links	3		Aluminum	Pressing/ Stamping	5	10	8	15
	Connecting link	2		Aluminum	Shaping			8	5
	Concentric tube	5		Plastic	Injection molding	3	10	1	13
	Shaft Assembly	30		Aluminum	Pressed	10	30	1	40

	Concentric tube holder	10		Plastic /Aluminum	Injection molding/ pressed stamped	3	7	1	10
	Shaft Spring	5		Steel	Rolling	3	17	1	20

5.3.5. Usability testing of Umbrella B and C

From design space theory, we have ergonomics and function connected together with usability for the user. The visual part of usability is in the form of aesthetics. Because of this framework we are doing a usability audit based on 5E principles of usability as environment, effectiveness, efficiency, easy to use and enjoyable (ISO20282, 9241 IEC14598, ISO/TR 16982:2002) [iso.org, 2017] as shown in Table 5.19.

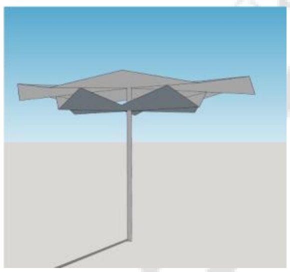
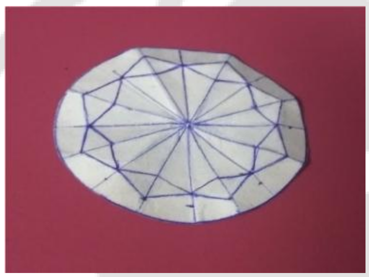
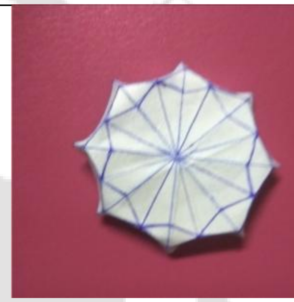
Table 5.19: Usability audit of umbrella

Parameter	**Details**	**Remarks/Problems**
Product Identification	Umbrella A	
User Identification		Any one above age 10 can use.
Environment	Workspace Work surface	1. In rainy seasons, and summer seasons. 2. Outside.
Effectiveness (Functional)	Features Limitation Consequences	1. Not 100% effective. Chance of legs getting wet. 2. Difficulty in using when it is windy. 3. Needs proper design of grip/handle. 4. Chance of toppling of umbrella in high winds. 5. Structure is weak since it is lightweight. 6. Big umbrellas when opened in crowded places consumes more space causing difficulty in moving.
Efficiency (Efficient)	Usable	Ratings given by the variety of customers and users are noted and they found umbrella A to be more efficient from the given 4 umbrellas.
Error free in use Safe	Safety	1.Fear of toppling. 2.Grip is also not ergonomically designed. 3.Wet conditions it is difficult to carry and store. 4.No locking mechanism, may cause problem for the kids.
Easy to use	User-friendly	1.Easy to use any one can operate easily. 2.No need of training or manual. 3.No part is detachable.

Enjoyable for use (Pleasurable)	User Experience	1. Variety of colors can make user happy, soft & ergonomics grips can be added, storage cover can be provided. 2. Low cost make user happy.

5.3.6. Identifying the spaces for further improvement and concepts generation

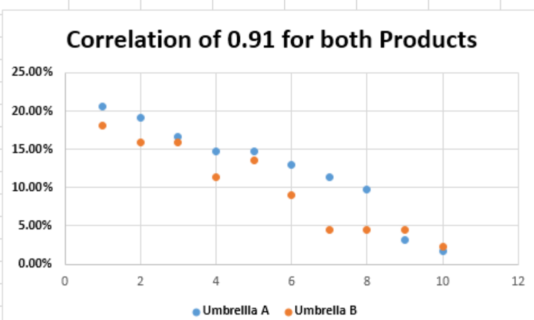
The same procedure is followed for the all the umbrellas. The areas of improvements are based on the above analysis. Minimizing the number of parts by combining the function in one, that will result in a very good product. Apart from these, we also list some more improvements such as using single arm, snap fit links, using standard components, make standard designs, using polymers instead of aluminum in majority of parts. Aesthetics and ergonomics can be improved in handle area. More pleasing colors can be added to the canopy (aqua colors). In summers a small fan can be added as value addition. Reverse folding of umbrella will solve the problem of drying and toppling.

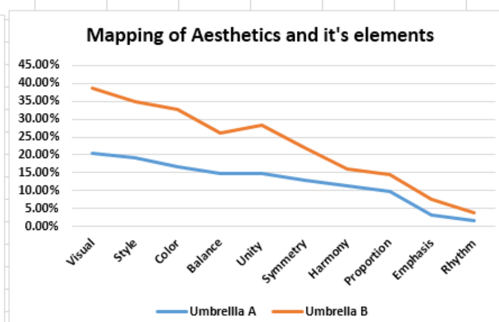
 **Concept 1**	 **Concept 2**	 **Concept 3**

5.3.7. Based on Prioritization of design elements for Umbrellas correlation, mapping and trends

Aesthetics

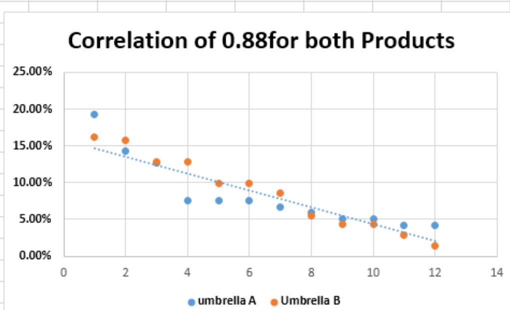
	Umbrellla A	Umbrella B
Visual	20.56%	18.16%
Style	19.16%	15.89%
Color	16.67%	15.89%
Balance	14.67%	11.35%
Unity	14.67%	13.62%
Symmetry	13.04%	9.08%
Harmony	11.41%	4.54%
Proportion	9.78%	4.54%
Emphasis	3.15%	4.54%
Rhythm	1.63%	2.27%
	91%	

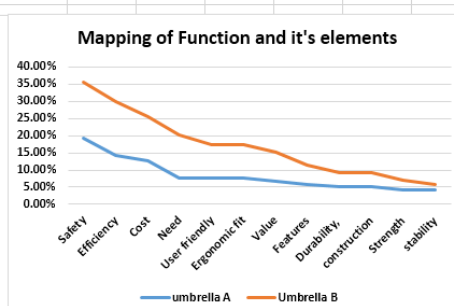




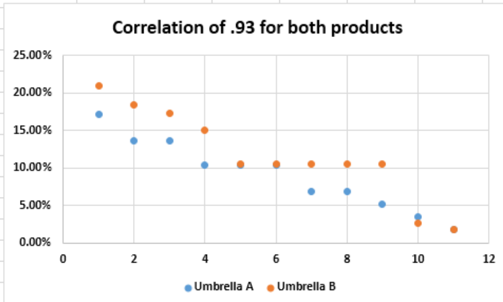
Function

	umbrella A	Umbrella B
Safety	19.32%	16.20%
Efficiency	14.28%	15.78%
Cost	12.67%	12.78%
Need	7.56%	12.78%
User friend	7.56%	9.94%
Ergonomic	7.56%	9.94%
Value	6.72%	8.52%
Features	5.88%	5.48%
Durability,	5.04%	4.26%
constructio	5.04%	4.26%
Strength	4.22%	2.84%
stability	4.22%	1.42%
	0.8805136	





Ergonomics		
	Umbrella A	Umbrella B
Safety	17.20%	21.04%
Efficiency	13.70%	18.41%
Reachabilit	13.70%	17.30%
Visibility	10.32%	15.03%
Force	10.32%	10.52%
Duration	10.32%	10.52%
Repetition	6.88%	10.52%
posture	6.88%	10.52%
Anthropom	5.16%	10.52%
Direction	3.44%	2.63%
Glance	1.72%	1.72%
	0.9398144	



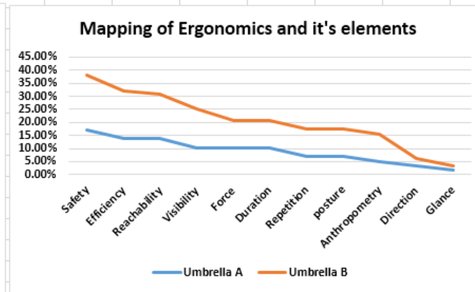


Figure 5.26: Aesthetics, Function and Ergonomics correlation and regression results and their trends

A correlation and regression analysis was computed for Umbrella A and B (Pearson product-moment correlation coefficient) to assess the trends of design elements (Prioritized) and their weights for both the products. There was a positive correlation between all the prioritized design elements r=0.91, n=10, p=0.00025 for aesthetics and its elements, r=0.93, n=11, p=1.72E-5 for ergonomics and its elements and for function and its elements are r=0.88, n=12, p=0.00015. Overall, there was a strong, positive correlation between prioritized design elements for both the products. These rankings and weights can be utilized precisely in designing phase. After mapping of all the elements, a similar trend was observed.

5.3.8. Overall results of linkographs developed

Detailed methodology followed in developing linkographs during the study of Umbrella

Our method utilizes quantitative and qualitative approach to develop linkography and is a method to analyze the design process followed in the initial phases of the product designing. Linkography is used for mapping how designers think? And generate creative ideas in a perceivable manner and combine them in a meaningful way. It has been seen that in a designing process the linkography is a logical way to get insights from cognitive psychology and a creative process [Goldschmidt, 1996]. Here, the main aim is to measure the linkography quantitatively even though the graph is plotted qualitatively. The objective of the plot/graph is to assess the productivity/innovativeness/goodness of the product, in the existing product or develop an entirely new product.

This study presents a method for evaluation of innovation index for the given set/class of products through the case study of problem i.e. 'How do we get protection against the rain? The solution quickly comes as umbrella, raincoats, caps, jerkins etc. But given two umbrellas or given two rain coats, how do we judge which is the best or relatively more innovative? It becomes very difficult to judge for users, designers and manufacturers. Our study develops a method which reports observations on the given product and it can tell relatively which is more innovative. Also the extended results can suggest further improvements of the products so that it can be more innovative by keeping user as the center i.e. user centered innovation.

Building of linkography: In the initial level we start by identifying the main design elements which influence the design of the product in order to achieve innovation along with their sub parameters. In one of our study we stated that innovation get influenced by many elements such as aesthetics, ergonomics, function, usability, operations, processes, materials, margin, marketing, assembly, manufacturing, competition, branding, public and policy. This wholly makes a fractal triangle of innovation as discussed in chapter 3.

Step 1: For the given product a user study has been conducted and then prioritization of design elements is done.

Step 2: For aesthetics, sub parameters are marked as design moves and each element is checked for the interrelationships. If they are related they are connected with points/dots called as nodes.

Step 3: Similar procedure is carried out for all identified design elements.

Step 4: Here we will be combining our design elements as per the fractal triangle of innovation i.e. aesthetics, ergonomics and function as one triangle to build bigger linkographs such as AEF. Similarly, linkographs for UPO considering usability, operations and processes are built. Now we have relationship within design elements and relationships between other elements along with sub parameters of others.

Analysis

The results were analyzed both qualitative and quantitatively. As a thumb rule of linkography, if it is very shallow with less number of links then the innovation index in the product is said to be very minimal in comparison with similar family of product or with the ideal one. On the other hand, if there are deep valleys in the linkographs then they have many more links. We can state that innovation index is high and it is more productive. The valleys can be measured in terms of the concentration of links in product design process.

Qualitative Observations

In the illustration of umbrella, we have taken 3 different kinds of umbrella for the analysis. Our study began with design audit of these products i.e. fish bone diagram for the improvements in the product and identification of the problems in the existing product. The value engineering help in understanding the components of the umbrella along with its function and to add/remove the components by reducing its cost. The engineering analysis is carried out in order to understand the product better in terms of materials, costing etc. As a part of the analysis the next phase of work will include the pair wise comparison of design elements, so that the result would give prioritized elements for the design process. The later stage is set for developing the linkographs for the identified design elements. Unlike the general architecture, here we use these linkographs in capturing the lost cognitive creativity/ideas while discussing, analyzing and getting/generating solutions. Through the protocol analysis linkographs are developed and analyzed both qualitative and quantitatively. In the case of umbrellas linkographs were developed. The study started from the theory of design space in which the user is at the center followed with a triangle constituted with aesthetics, ergonomics and function as its edges.

From the current example of umbrellas, A, B, and C, let us take umbrella as product A, and start building the linkographs after carrying the design audit as mentioned in the earlier part. In developing linkographs at the first level, individual factors such as ergonomics, aesthetics and functions were considered. It is then combined to build a single linkograph as AEF, as shown below. At second level, the building of second triangle elements i.e. usability, processes and operations was combine to build a single linkograph as UPO.

By plotting all the elements coming under function such as strength, durability, cost/value, purpose, fit, features, stability, construction, ease of use etc. as shown in the Fig. 5.27. These elements are then linked to each other based on whether the parameter is related or not.

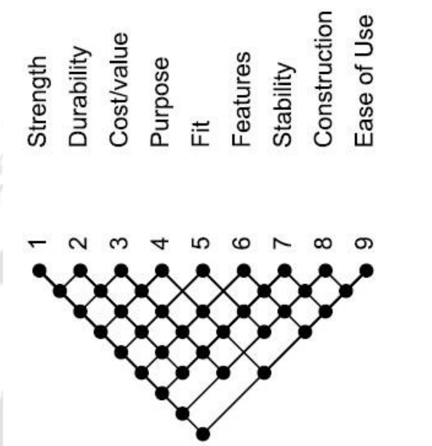


Figure 5.27: Showing a linkograph of function along with its design elements

Construction of the linkographs:

1. To start with, a question is posed: Is strength related to durability? If yes, then connect/establish a link between strength to durability.

2. Is strength related to cost/value? If yes, then connect/establish a link between strength to cost.

3. Is strength related to purpose? If yes, then connect/establish a link between strength to purpose.

4. Is strength related to fit? If no, then do not connect/establish a link between strength and fit.

5. Similarly features with no link/relation are left blank and the same procedure is followed until all the sub parameters are checked.

6. Is durability related to cost? If yes, then connect/establish a link between durability and cost and apply the same procedure to build an entire linkograph for function, for umbrella A (product A)

The linkograph developed is for the function and similar steps are followed to develop linkographs for ergonomics and aesthetics individually.

7. The next step would be combining all the design elements falling in each of aesthetics, ergonomics & function and plot the linkograph by identifying the relations with each other. It will be constituted of all design elements of AEF to form design moves.

8. Repeat the same procedure for the second triangle considered as UPO and build the linkograph individually as well as combined, as shown in following section.

9. Analyze the linkograph and interpret in terms of their relations i.e. where should more emphasis be given? Where are greater number of links?

This is the overall building of the linkograph for product A, similar procedure is carried for remaining products i.e. B, C, D umbrellas and raincoat.

5.3.9. Linkograph results

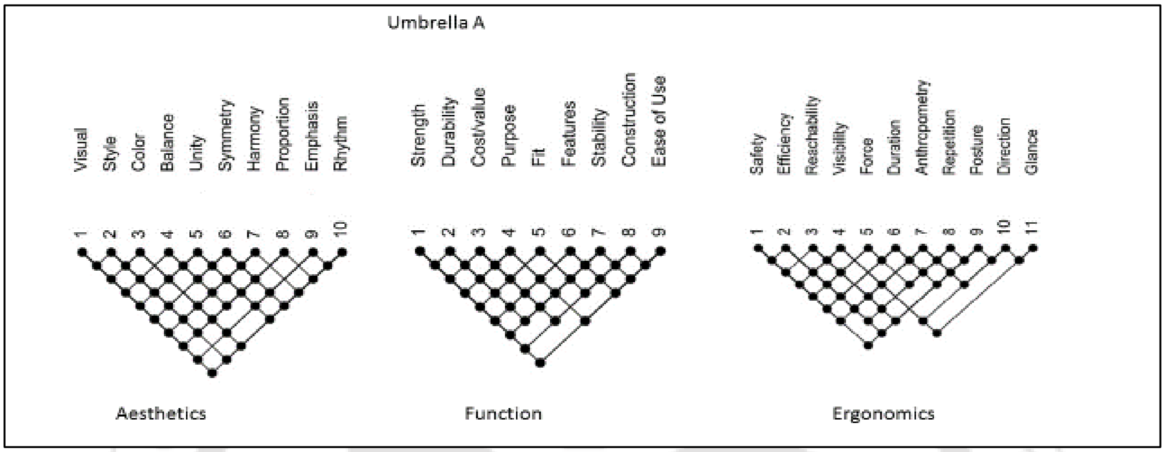


Figure 5.28: Showing a linkograph of function, ergonomics and aesthetics individually along with their design elements

Aesthetics

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9
10 (36)	3.5	-	0.5	0.2	0.2	0.1	0.1	0.1

Ergonomics

Number of moves N	Link index L.I	%CM3	%CM5	%CM6	%CM7
11 (32)	2.9	0.63	0.27	0.18	0.09

Function

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM6	%CM8
9 (28)	3.1	0.33	0.33	0.33	0.11	0.11

Combined AEF

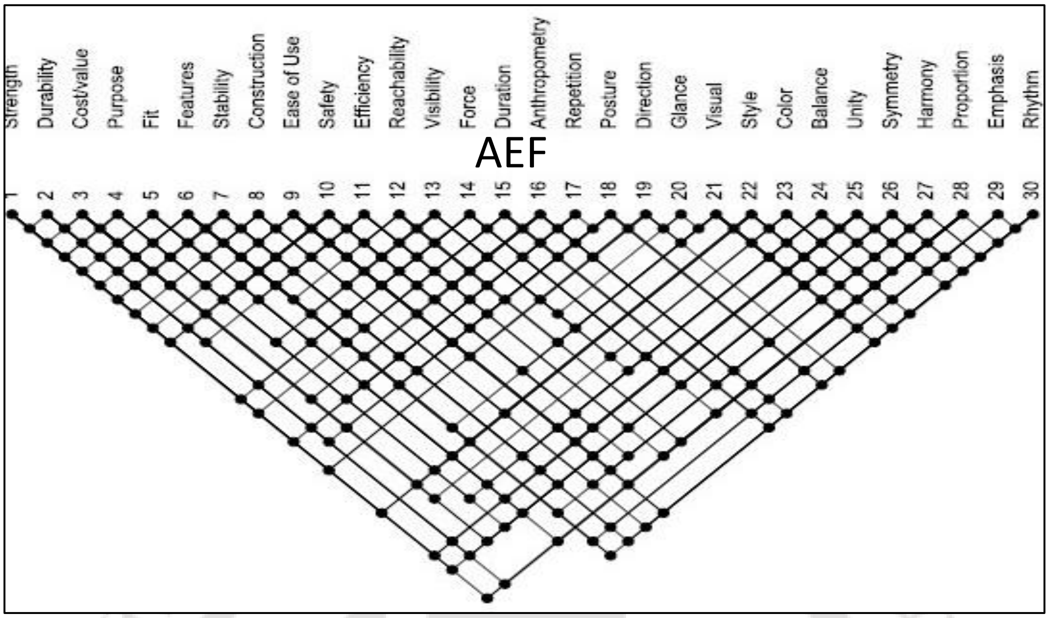


Figure 5.29: Showing a linkograph of aesthetics, ergonomics & function combined along with their design elements

Aesthetics + Ergonomics + Function (AEF)

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	%CM10	%CM11	%CM13	%CM14	%CM15	%CM16	%CM18
30 (207)	6.9	0.13	0.2	0.16	0.16	0.16	0.13	0.03	0.03	0.16	0.1	0.06	0.06	0.03	0.03

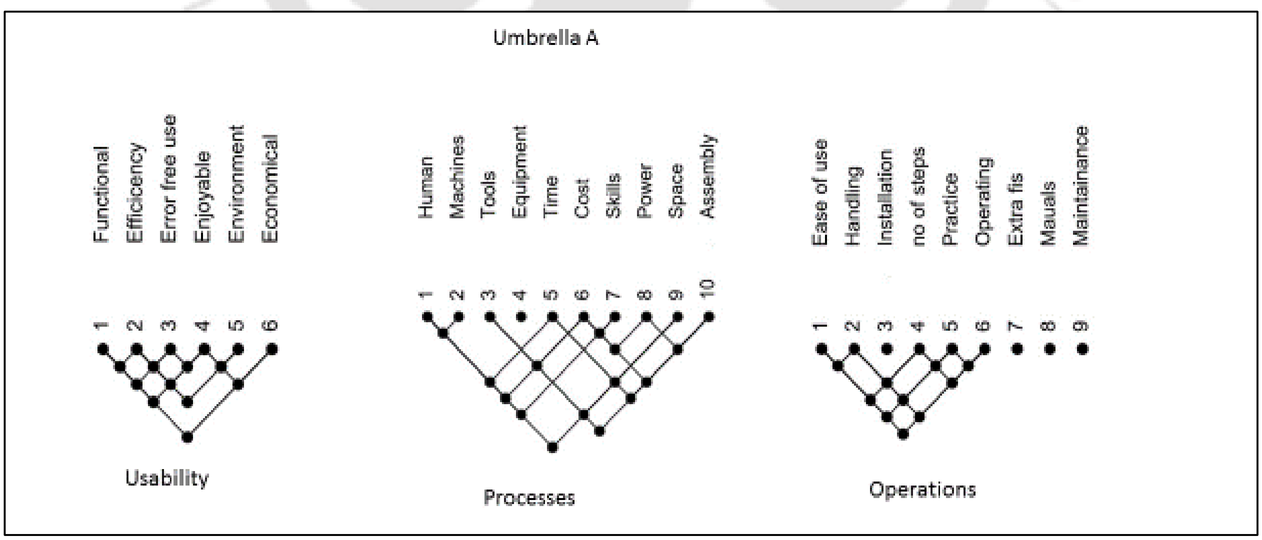


Figure 5.30: Showing a linkograph of usability, processes, operations individually along with their design elements

Usability

Number of moves N	Link index L.I	%CM3	%CM4	%CM5
6 (10)	1.6	0.33	0.16	-

Processes

Number of moves N	Link index L.I	%CM3	%CM4	%CM6	%CM7
10 (14)	1.4	0.3	0.1	0.1	-

Operations

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM7
9 (10)	1.11	0.22	0.22	-	-

Combined UPO

Usability + Processes + Operations

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	%CM10	%CM11	%CM12	%CM16
25 (112)	4.84	0.2	0.12	0.08	0.16	0.08	0.12	0.04	0.16	0.12	0.04	0.04

UPO

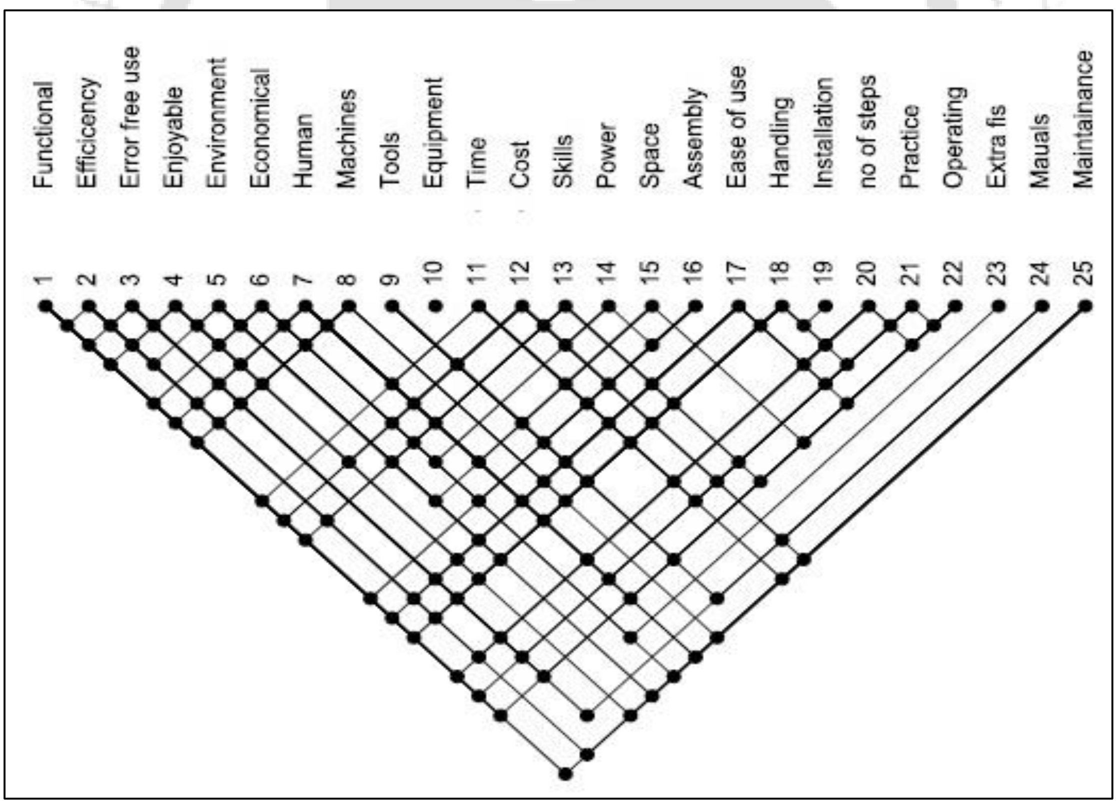


Figure 5.31: Showing a linkograph of usability, processes & operations combined along with their design elements

Umbrella B and C

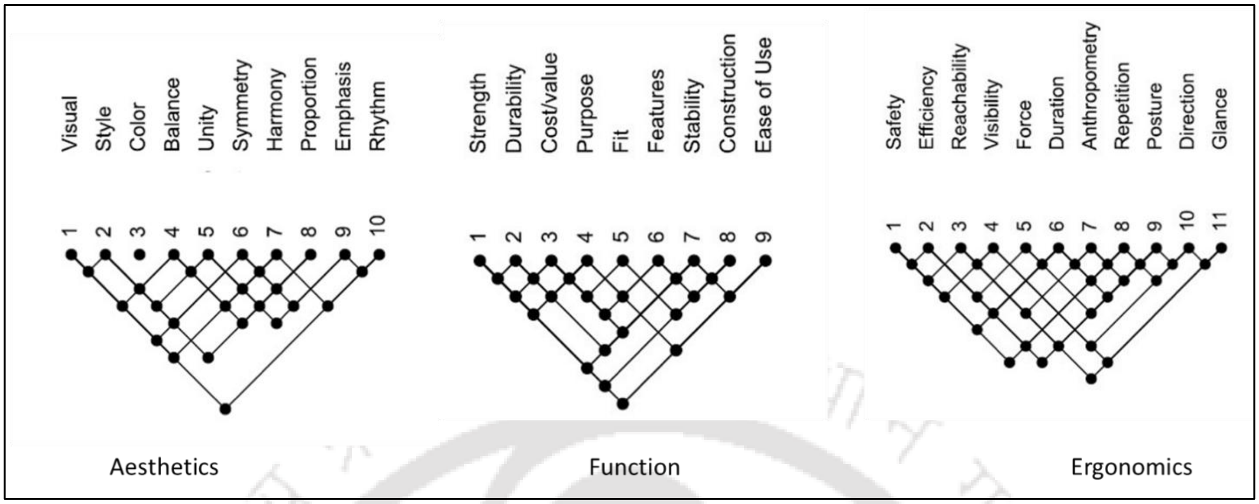


Figure 5.32: Linkographs of umbrella B and C along with their design elements

Function

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM7
9 (20)	2.22	0.33	0.33	-	0.11

Ergonomics

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM7
11 (26)	2.3	0.36	0.27	0.18	-

Aesthetics

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM6	%CM7
10 (19)	1.9	0.4	0.3	0.1	-	-

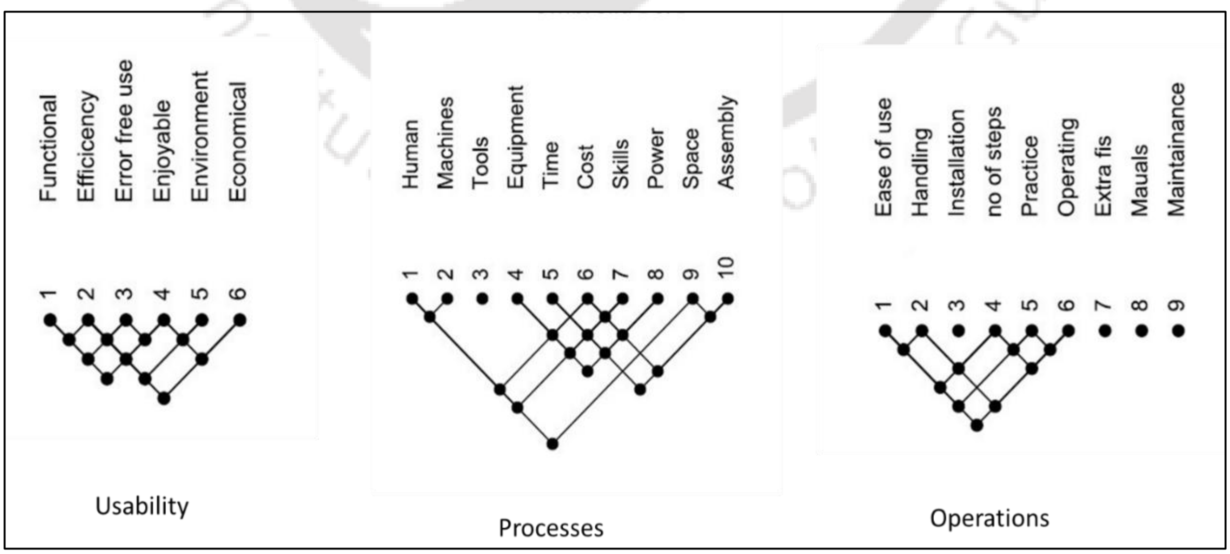


Figure 5.33: Linkographs of umbrella B and C along with their design elements

Usability

Number of moves N	Link index L.I	%CM3	%CM4	%CM5
6 (10)	1.6	0.33	0.16	-

Processes

Number of moves N	Link index L.I	%CM3	%CM4	%CM6
10 (14)	1.4	0.5	0.2	-

Operations

Number of moves N	Link index L.I	%CM3	%CM4	%CM5
9 (10)	1.11	0.11	0.22	-

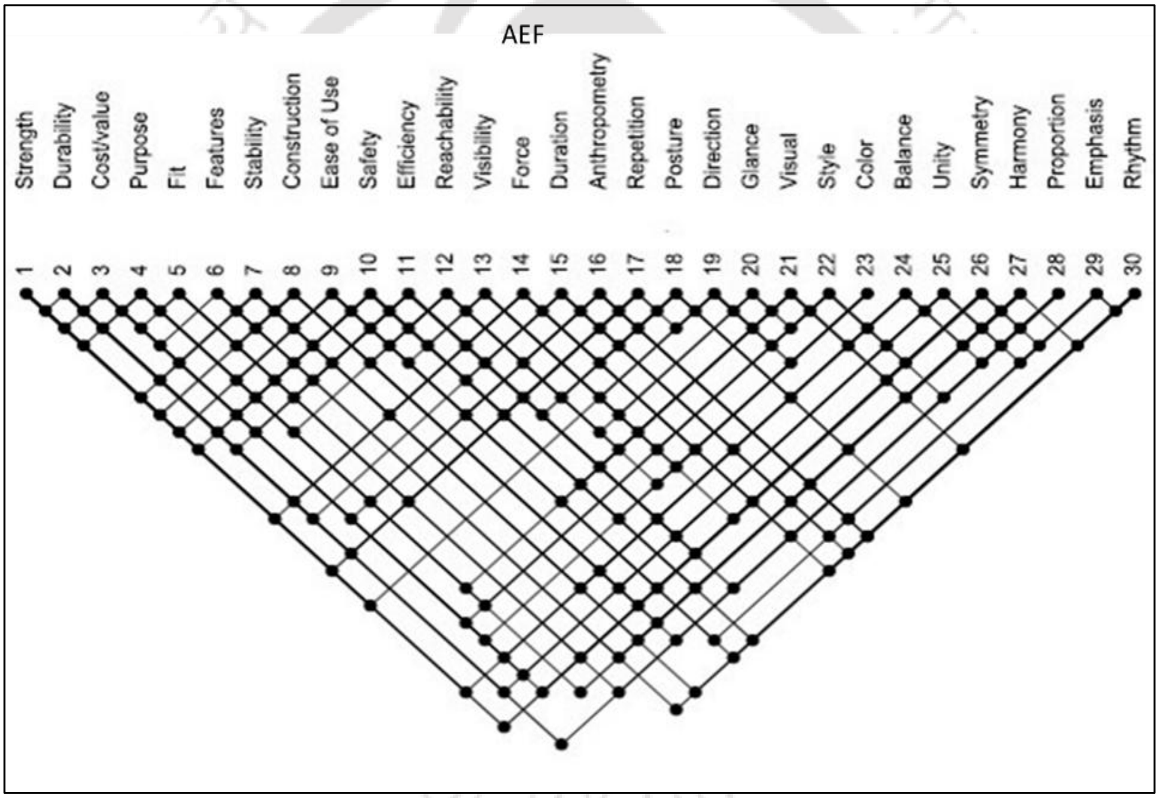


Figure 5.34: Linkographs of umbrella B and C along with their design elements

Aesthetics + Ergonomics + Function (AEF)

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	%CM10	%CM11	%CM12
30(156)	5.2	0.23	0.3	0.13	0.33	0.1	0.13	0.016	0.06	0.03	0.1

Usability + Processes + Operations(UPO)

Number of moves N	Link index L.I	%CM 3	%CM 4	%CM 5	%CM 6	%CM7	%CM8	%CM9	%CM 10	%CM1 3
25(100)	4	0.2	0.2	0.2	0.04	0.04	-	0.2	0.2	0.04

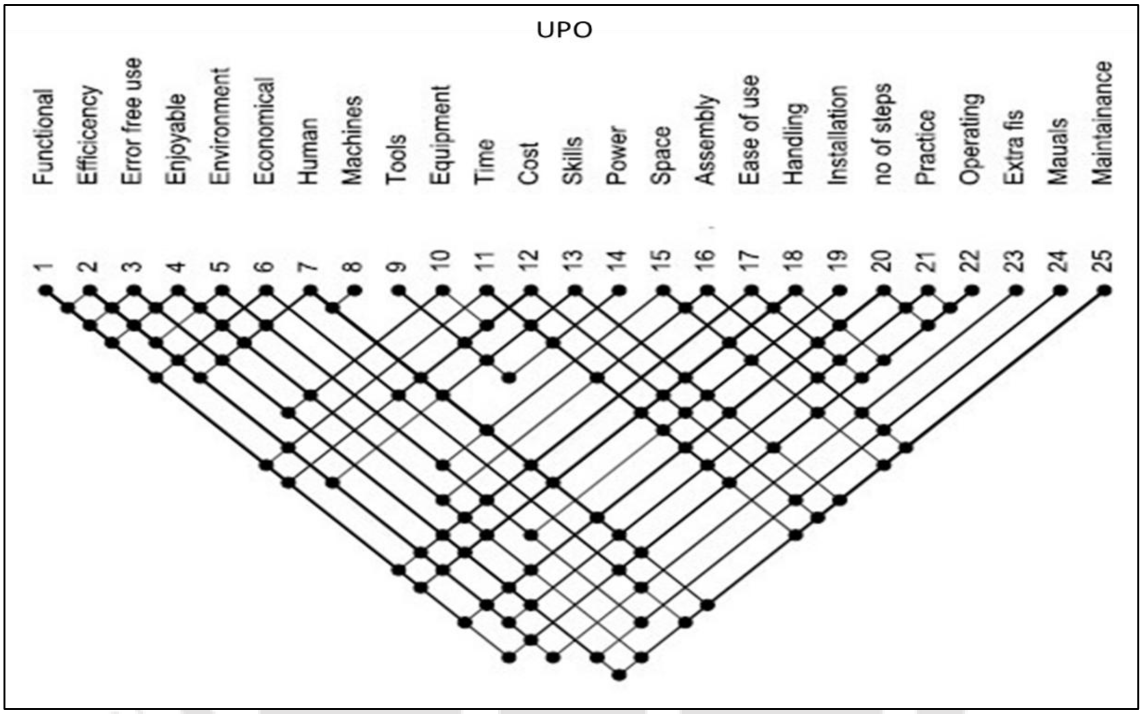


Figure 5.35: Linkographs of umbrella B and C along with their design elements

Rain coat

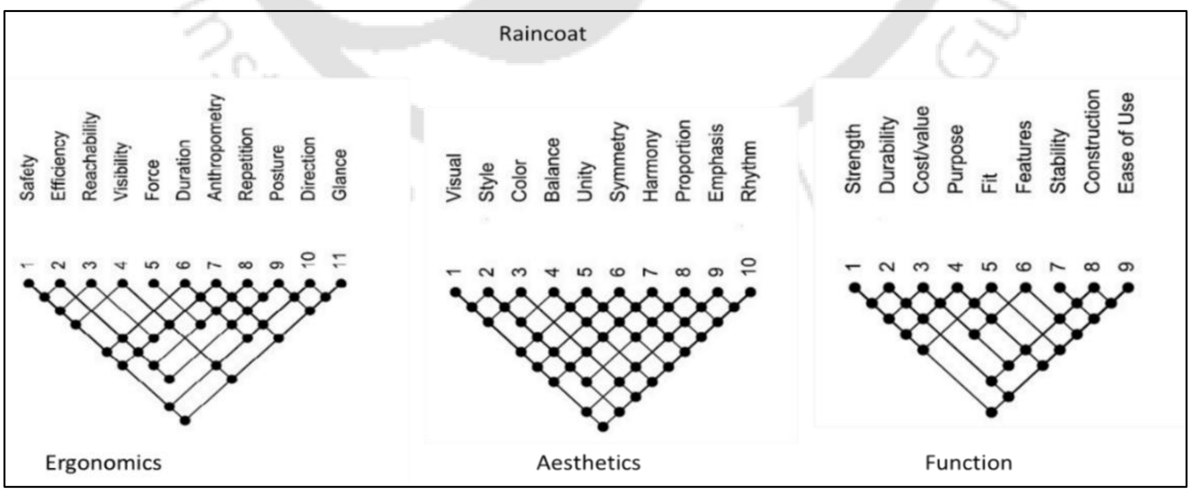


Figure 5.36: Linkographs of raincoat along with their design elements

Function

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM7
9 (22)	2.4	0.22	0.22	0.22	0.11

Ergonomics

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM7
11 (28)	2.5	0.09	0.45	0.27	0.09

Aesthetics

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM6	%CM7	%CM9
10 (35)	3.5	0.3	0.5	0.1	0.2	0.2	.1

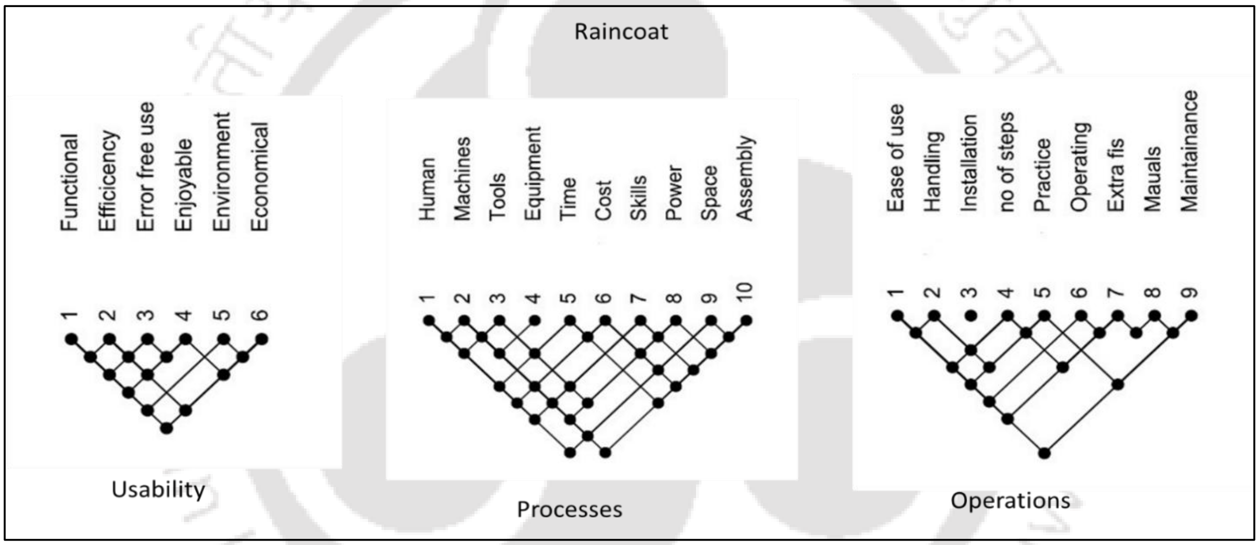


Figure 5.37: Linkographs of Raincoat along with their design elements

Usability

Number of moves N	Link index L.I	%CM3	%CM4	%CM5
6 (11)	1.83	0.33	0.16	0.16

Processes

Number of moves N	Link index L.I	%CM3	%CM4	%CM6	%CM7
10 (25)	2.5	0.5	0.1	0.2	0.2

Operations

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM7
9 (14)	1.55	0.3	-	-	0.11

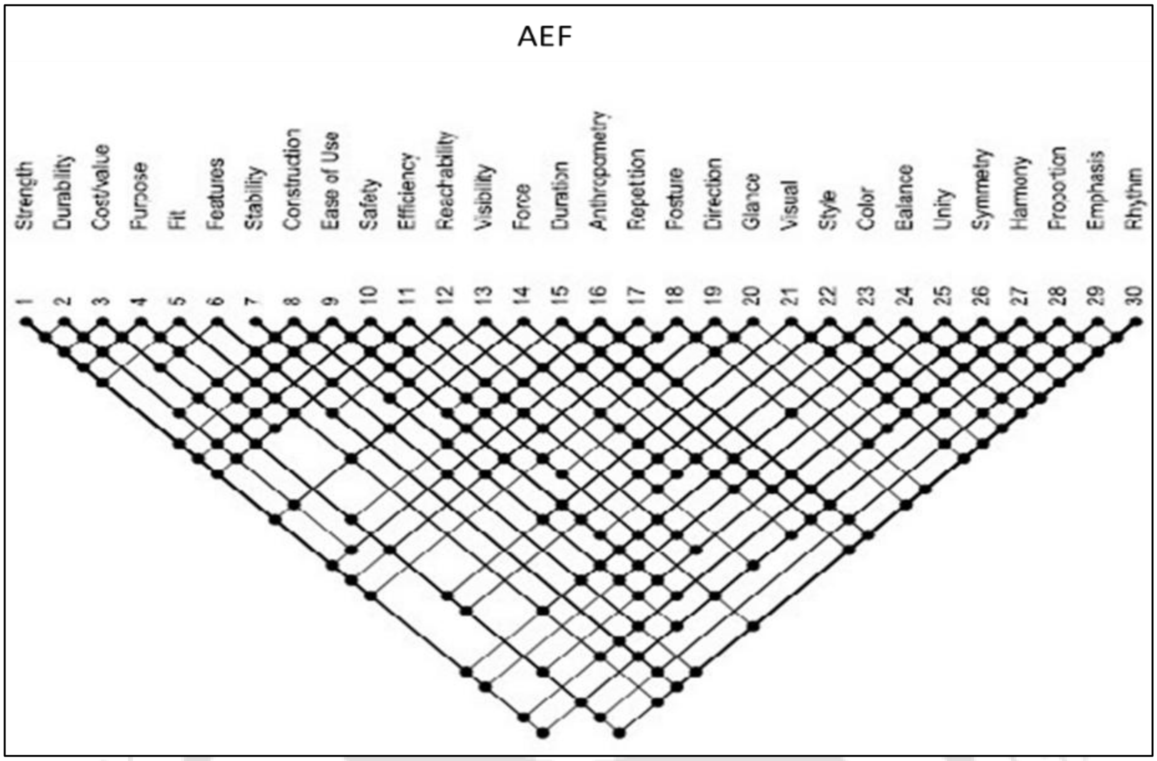


Figure 5.38: Showing combined AEF linkograph

Aesthetics + Ergonomics + Function(AEF)

Number of moves N	Link index L.I	%CM3	%CM4	%CM6	%CM7	%CM8	%CM9	%CM10	%CM11	%CM13	%CM14	%CM15	%CM18
30 (180)	6	0.2	.2	0.2	0.23	0.13	0.2	.03	.03	.06	.06	.03	.03

Usability + Processes + Operations(UPO)

Number of moves N	Link index L.I	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	%CM11	%CM12	%CM14
25 (121)	4.84	0.24	0.12	0.12	0.12	0.2	0.04	0.2	0.08	0.12	0.04

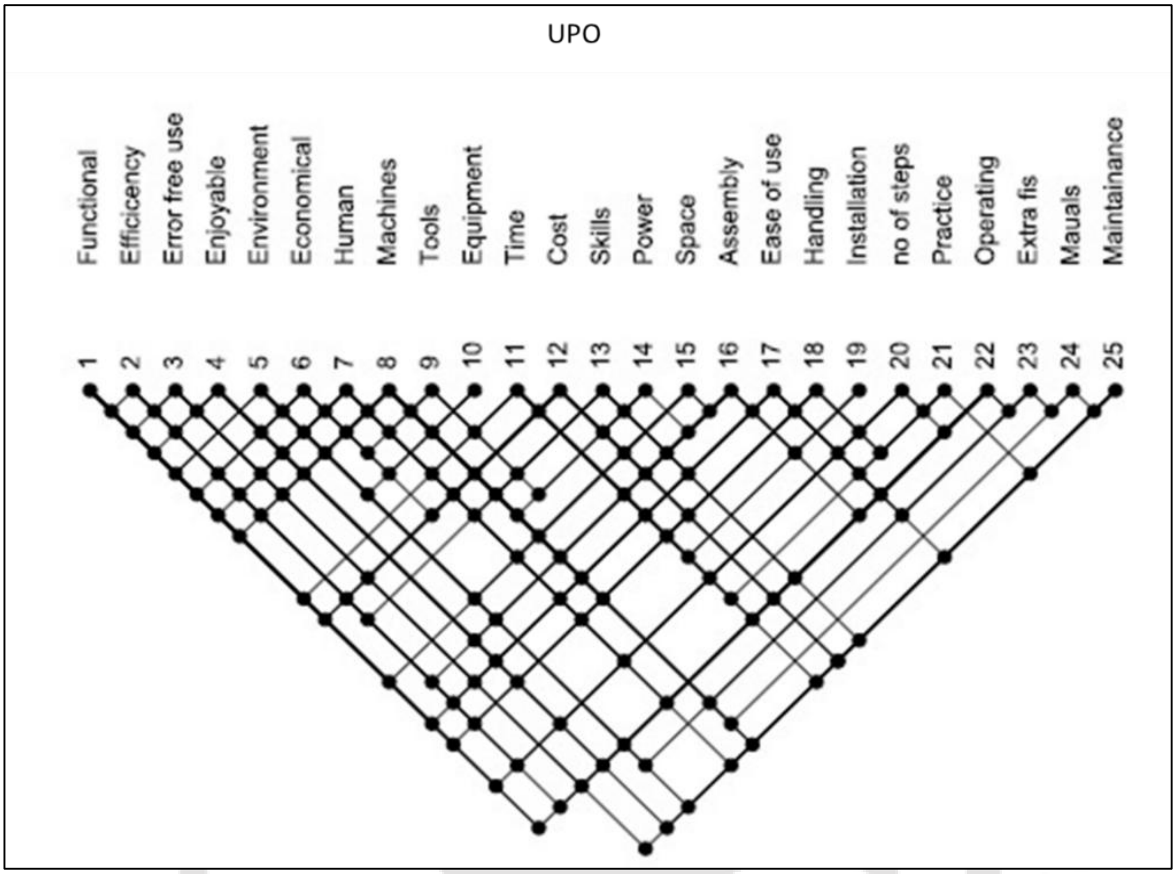


Figure 5.39: Showing combined UPO linkograph

Quantitative measures

Gold Schmidt [1996] uses the number of links proportional to the number of moves as Link Index (LI). It as an indicator of the strength or productivity of the design process [Kan & Gero, 2004].

Kan and Gero interpret Link index as "productivity of design process", according to them they have plotted the discussions of designers (recorded) for 1st 20 minutes as linkographs. The linkographs are decoded and analyzed for link index. If the links are more, greater is the productivity (process of idea development). Hence they term this as productivity of design process.

In our research the parameters influencing innovation in product design are considered (Fractal triangle of innovation). The linkographs are plotted and link index are generated. The graphs will show the spots of value addition in terms of design elements (Missing links), it is nothing but the innovation in micro steps. Hence, we term it as innovation index. It is compared with other product of same family therefore, now it is referred to as relative innovation index.
Based on our subjective evaluation we call it as relative innovation index, i.e. as the LI increases the innovation increases. Increase in the number of links in the linkograph increases the innovation index.
For any product if linkographs are developed at first glance it gives an idea of where and how design elements are related? Which are the elements missing in the design act? It is a cognitive process while establishing the relations/connections between the moves of linkograph.

The moves with intense/highly dense links are called critical moves (CM) and it allows us to compare different design processes quantitatively. A higher link index value suggests it is a relatively innovative product.

Table 5.20: Consolidated results umbrella A, B, C and raincoat with their link index and CM

	A	E	F	AEF	U	P	O	UPO
Umbrella A	3.5	2.9	3.1	6.9	1.6	1.4	1.11	4.84
Umbrella B	1.9	2.3	2.22	5.2	1.6	1.4	1.11	4
Umbrella C	1.9	2.3	2.22	5.2	1.6	1.4	1.11	4
Raincoat	3.5	2.5	2.4	6	1.83	2.5	1.55	4.84

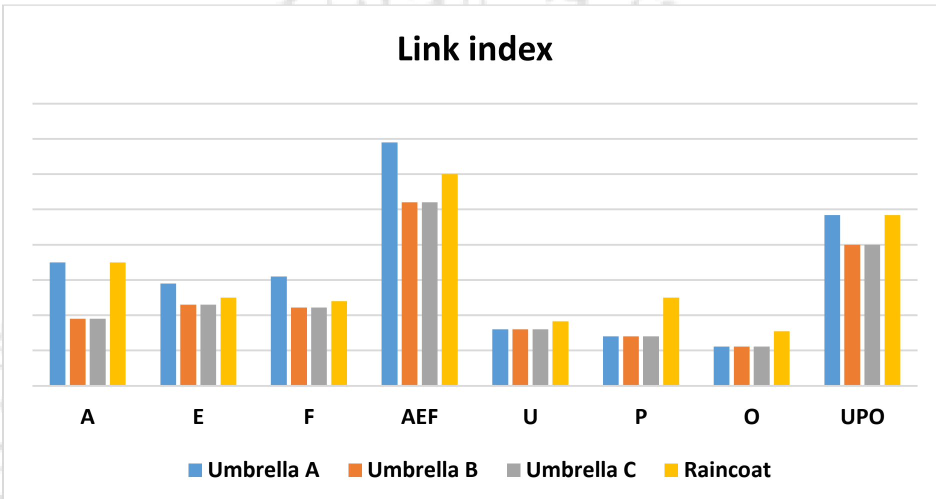


Figure 5.40: Link index for Umbrella A, B, C and raincoat

The Fig. 5.40 shows the individual, combined link index of design elements for all the products. From Table 5.20 and the above graph it is observed that the link index of umbrella A and raincoat are higher in all aspects. Hence, making them more value added than others. This implies that higher the link index higher is the value added and that makes it more innovative.

Table 5.21: Consolidated results umbrella A, B, C and raincoat %CMs for AEF

	% CM5	% CM6	% CM7	% CM8	% CM9	% CM10	% CM11	% CM12	% CM13	% CM14	% CM15	% CM16	% CM17	% CM18
A	0.16	0.16	0.16	0.13	0.03	0.03	0.16		0.1	0.06	0.06	0.03		0.03
B	0.13	0.33	0.1	0.13	0.016	0.06	0.03	0.1						
C	0.13	0.33	0.1	0.13	0.016	0.06	0.03	0.1						
Raincoat		0.2	0.2	0.13	0.2	0.03	0.03		0.06	0.06	0.03			0.03

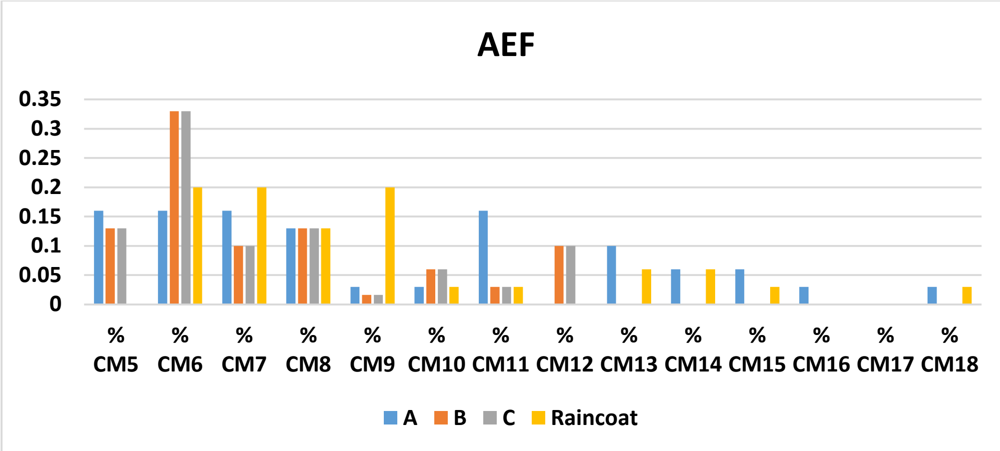


Figure 5.41: Consolidated % CMs for Umbrella A, B, C and raincoat AEF

The Fig. 5.41 shows the percentage critical moves in terms of aesthetics, ergonomics and function for all the products. The Table 5.21 and the graph, indicates the link index of both products along with % critical moves. This indicates the depth of the relations built and granularity of the analysis.

Table 5.22: Consolidated results Umbrella A, B, C and Raincoat %CMs for UPO

	% CM5	% CM6	% CM7	% CM8	% CM9	% CM10	% CM11	% CM12	% CM13	% CM14	% CM15	% CM16
A	0.08	0.16	0.08	0.12	0.04	0.16	0.12	0.04				0.04
B	0.2	0.04	0.04		0.2	0.2			0.4			
C	0.2	0.04	0.04		0.2	0.2			0.4			
Raincoat	0.12	0.12	0.2	0.04	0.2		0.08	0.12		0.04		

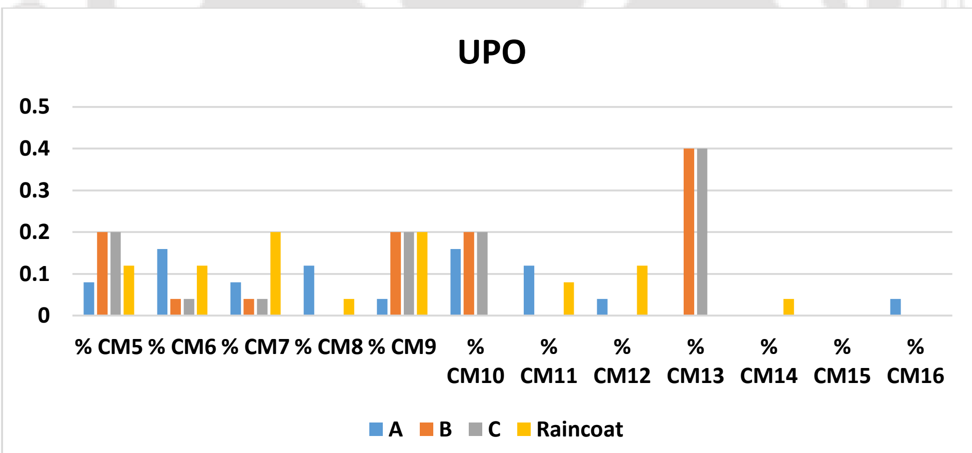


Figure 5.42: Consolidated percentage CMs for Umbrella A, B, C and raincoat UPO

The Fig. 5.42 shows the percentage critical moves in terms of usability, processes and operations for both the products. The Table 5.22 and the above graph indicates the link index of both products along with % critical moves. This indicates the depth of the relations built and granularity of the analysis. From the previous chapter, we had posed the question w.r.t the umbrellas and their innovativeness. From the result analysis, we can observe that out of the given umbrellas, the one having highest link index is more innovative (product A).

Table 5.23: Overall linkographs developed for Umbrellas A, B and C

	No of Moves N	Link Index LI	%CM 3	%CM4	%CM 5	%CM6	%CM 7	%CM 8	%C M 9	
Umbrella A	9	3.5		0.5	0.2	0.2	0.1	0.1	0.1	Aesthetics
Umbrella B & D	9	1.9	0.4	0.3	0.1					
Umbrella A	11	2.9	0.63	0.27	0.18	0.09				Ergonomics
Umbrella B & D	11	2.3	0.36	0.27	0.18					
Umbrella A	10	3.1	0.33	0.33	0.33	0.11	0.11			Function
Umbrella B & D	10	2.22	0.33	0.33		0.11				
Umbrella A	10	1.11	0.22	0.22	-	-				Operations
Umbrella B & D	10	1.11	0.11	0.22	-					
Umbrella A	10	1.4	0.3	0.1	0.1	-	1.4	0.3		Processes
Umbrella B & D	10	1.4	0.5	0.2	-	1.4	0.5	0.2		
Umbrella A	6	1.6	0.33	0.16						Usability
Umbrella B & D	6	1.6	0.33	0.16						

Hence, from the Table 5.23 we conclude that umbrella A, link index is 3.5 and umbrella B and D is 1.9, the difference obtained is the relative innovation index. Umbrella A is more value added than the umbrella B & D in Aesthetics. Similarly, umbrella A is more value added than umbrella B & D ergonomically. Functionally umbrella A has index of 0.88 in terms of function w.r.t B & D. Operation, usability and process wise umbrella A, B & D are all same. By observing all the results of individual design elements, umbrella A has higher values and that makes it more innovative in comparison with the umbrella B & D.

Combined AEF

Table 5.24: Combined results of Aesthetics, Ergonomics and Function

	LI	%CM3	%CM 4	%CM 5	%CM 6	%CM 7	%CM 8	%CM 9	%CM 10	%CM 11	%CM 12	%CM 13	%CM 14	%CM 15	%CM 16	%CM 17	%CM 18	%CM 19	%CM 20
Umbrella A	6.9	0.13	0.2	.16.2	.16	.16	.13	.03	.03	.16	.1	.06	.06	.03	.03	6.9	0.13	0.2	.16.2
Umbrella B & D	5.2	0.23	.3	.13	0.33	0.1	0.13	.016	.06	0.03	.1	5.2	0.23	.3	.13	0.33	0.1		
Raincoat	6	0.2	.2	0.2	0.23	0.13	0.2	.03	.03	.06	.06	.03	.03	6	0.2	.2			

Combined UPO

Table 5.25: Combined results of Usability, Processes, Operations

	LI	%CM3	%CM 4	%CM 5	%CM 6	%CM 7	%CM 8	%CM 9	%CM 10	%CM 11	%CM 12	%CM 13	%CM 14	%CM 15	%CM 16	%CM 17	%CM 18	%CM 19	%CM 20
Umbrella A	4.84	0.2	0.12	0.08	0.16	0.08	0.12	0.04	0.16	0.12	0.04								
Umbrella B & D	4	0.2	0.2	0.2	0.04	0.04	-	0.2	0.2	0.04	0.04	0.2							
Raincoat	4.84	0.24	0.12	0.12	0.12	0.2	0.04	0.2	.08	0.12	0.04		0.24						

When all the design elements are combined such as aesthetics, ergonomics and function, the link index of umbrella A is the highest i.e. value of 6.9. And in case of usability, operations and processes the umbrella A and rain coat are similar with value of 4.84. The step wise procedure leading to the construction of the proposed model is shown below.

The product analysis highlights the areas of improvement in terms of the added value. Based on the product analysis the linkographs clearly indicates the areas of improvement, so that value can be added. From the linkographs we can deduce that lesser the link, lesser is the relation to design elements. This can be observed in the linkographs developed. Hence, on comparing linkographs we can locate the spots for value addition by building up the relations. The cognitive design thinking sometimes connects to the design elements and makes the product more innovative. This is not a very common occurrence.

5.4. Case study 3, Product 3, Envelope making setup-2 types

5.4.1. Chinese made envelope maker

(One is made in China and is costly and the other is lab developed as envelope A & B)

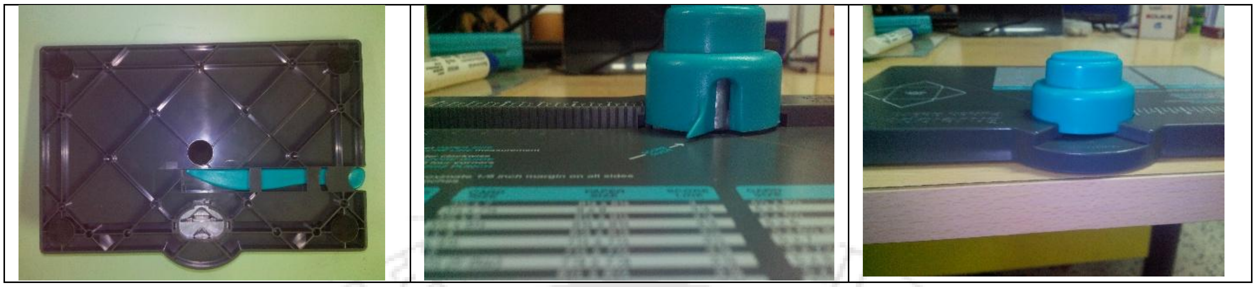


Figure 5.43: Chinese made envelope maker and its parts

Along with product analysis, we raised questions such as, 1) Design methods lead to more productive and value-added product? 2) Sheer innovation potential decides the best concept amongst the developed ideas?

To identify the solution, the results are analyzed and discussed in the next chapter. In this case study, we are demonstrating the concept selection matrix for evaluation of generated concepts.

Product A Chinese made envelope maker

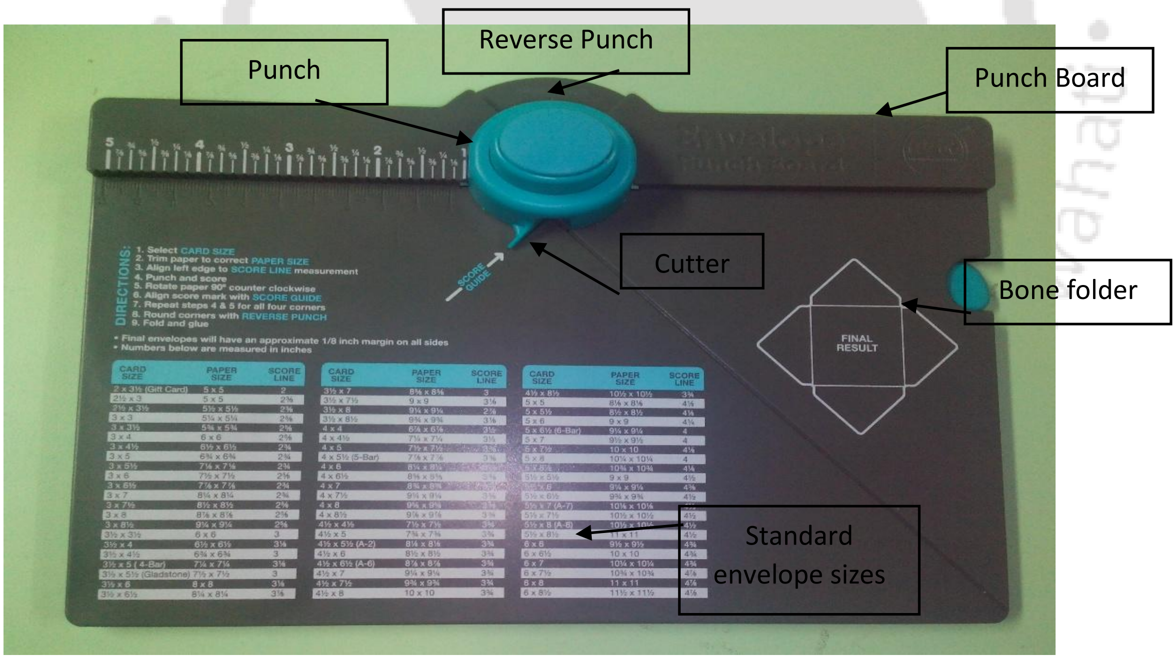


Figure 5.44: Envelope making setup Chinese made

Product B Developed in our Lab

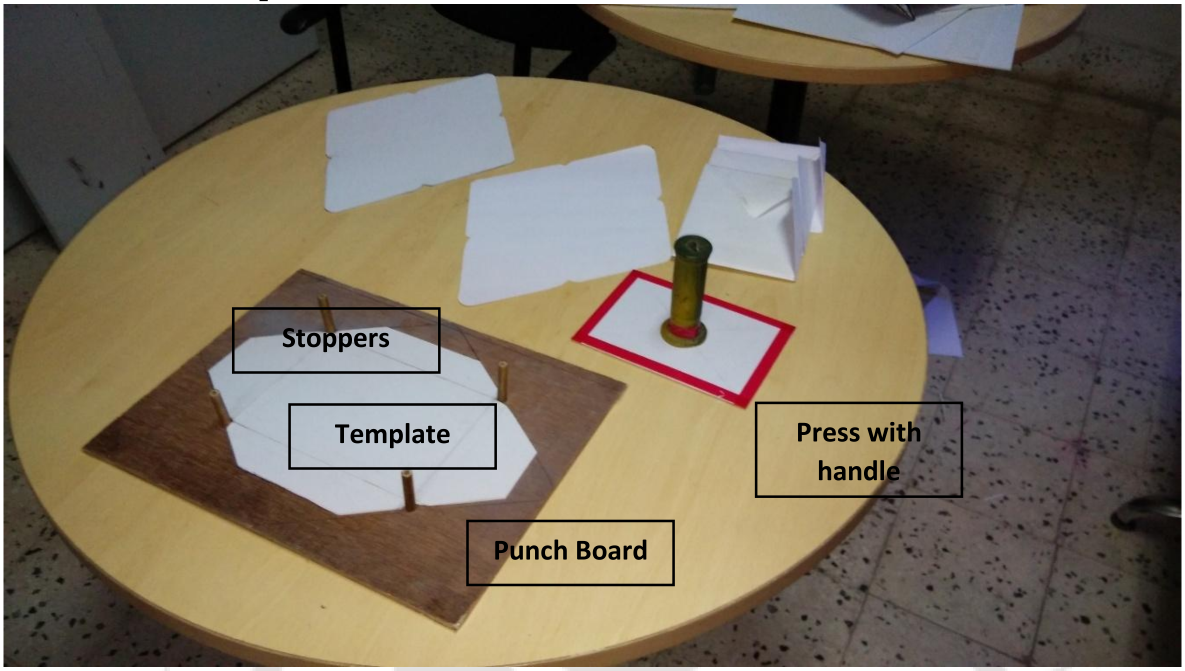


Figure 5.45: Envelope making setup developed in the lab

5.4.2. Fish bone diagram for both Envelope maker, Chinese made A and developed in IITG lab B

Fish bone diagram for both the products are as follows

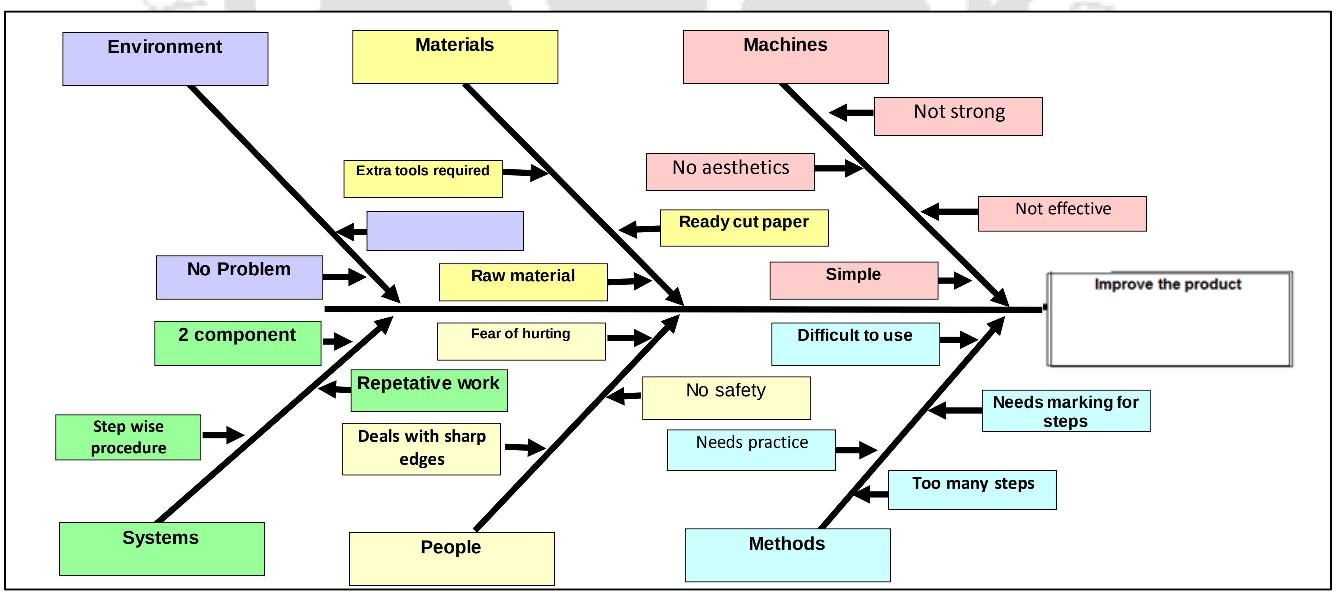


Figure 5.46: Fish bone diagram for the envelope maker done at IITG Lab

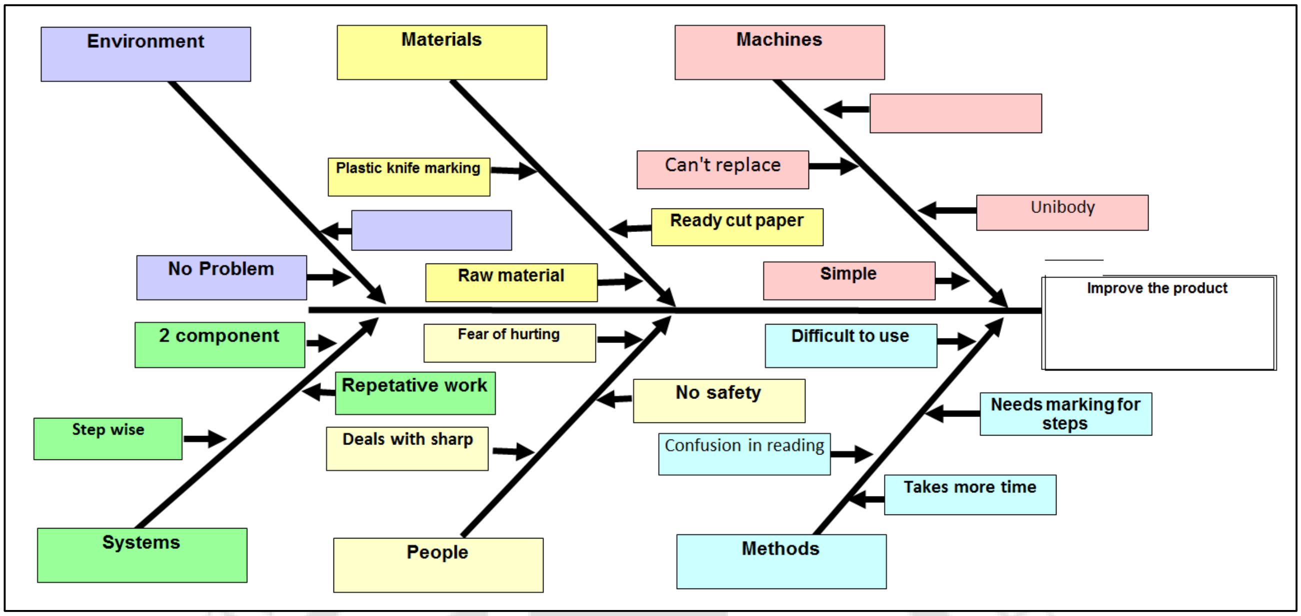


Figure 5.47: Fish bone diagram for the envelope maker Chinese made

5.4.3. Value engineering and Value analysis of the product A (Chinese made envelope maker)

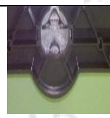
Table 5.26: Value engineering of Chinese envelope maker

Sl. No.	No. of Parts	Component	Function	Material	Importance to customer	Cost in Rs.	%	Need of alteration and reason	Priority of redesign
1	1	Board	Support	Hard Plastic	High	600	73.17	No	1
2	1	Punch assembly	Housing for cutter Pressing	HDP	Medium	80	9.75	Yes, as it is non detachable	3
3	1	Cutter	Cutting	Steel	Low	100	12.19	Yes, as it is a complete assembly, it can't be replaced	2
4	1	Plastic knife	Scoring/marking	Plastic	Medium	25	3.02	No	4
5	1	Scorecard	Size marking	Paper/sticker	Medium	10	1.2	No	5

The cost at which the Chinese firm is selling is too high, i.e. Rs. 1900/- but the calculated costs are Rs. 820/-. Hence, we will consider Rs. 820/- for our calculations.

5.4.4. Engineering analysis of Chinese made envelope maker

Table 5.27: Engineering analysis of Chinese envelope maker

Sl. No.	Component	Figures	Material	Process	Properties	Fixed costs	Variable costs	Volume	Total Unit Cost in Rs.
1	Board		Hard Plastic	Injection molding	Strength, durable, last longer is good	50	550	1	600
2	Punch assembly		HDP	Injection molding	Strength, durable, last longer is good	30	50	1	80
3	Cutter		Steel	Hard pressed and machined	Durable, good strength	20	80	2	100
4	Plastic knife		Plastic	Injection molding	Hard , finishing good	5	20	1	25
5	Scorecard		Paper/sticker	Printed on a sticker	Informative,	5	5	1	10

5.4.5. Usability Audit- of Product A Chinese made envelope maker

Table 5.28: Usability audit of Chinese made envelope maker

Parameter	**Details**	**Remarks/Problems**
Product Identification	Product A: Chinese made Envelope maker	
User Identification		Any one above age 15 can use.
Environment	Workspace Work surface	1. Anywhere, can be used on a table.
Effectiveness to use (Functional)	Features Limitation Consequences	1. 100% effective. More attention is needed in selecting the size of the envelope. 2. Required size and paper should be selected with prior cut.

		3. Proper score as mentioned on the board should be maintained.
Efficiency to use (Efficient)	Usable	Above average ratings given by the variety of customers and users.
Error free to use (Safe)	Safety	1. Confusion in holding the paper as it looks the same from all angles. 2. The cutter may become blunt.
Easy to use	User-friendly	1. Easy to use, anyone can operate easily, kids can use under adult supervision. 2. No need of training or manual. 3. All parts are covered.
Enjoyable to use (Pleasurable)	User Experience	Feels good while using, Cost is very high for an individual user

5.4.6. Value engineering and Value analysis of the product Envelope B developed in Lab

Table 5.29: Value engineering of product Envelope B developed in lab

Sl. No.	No of Parts	Component	Function	Material	Importance to customer	Cost in Rs.	%	Need of alteration and reason	Priority of redesign
1	1	Board	Support	Wood	High	40	26.66	No	
2	4	Stoppers	Housing for cutting and folding	Wood	Medium	10	6.66	No	
3	1	Cutter	Cutting	Steel	Low	25	16.66	No	
4	1	Press with handle	Pressing and holding	Rubber Wood	High	15	10	No	
5	1	Folding template	Size marking	Plastic sheet	Medium	60	40	No	

The cost of the product is Rs. 150/-. Actually, this product has been developed from the concept to working model in UE-HCI lab IIT Guwahati. We have used the available resources and made this product. In this, we have to pre-cut the required size of paper and use it.

5.4.7. Engineering analysis of Product Envelope B developed in Lab

Table 5.30: Engineering analysis of product Envelope B developed in lab

Sl. No.	Component	Figures	Material	Process	Properties	Fixed costs	Variable costs	Volume	Total Unit Cost in Rs.
1	Board		Wood	Ply, pressed	Strength, durable,			1	40

					last long is good				
2	Stoppers		Wood	Circular sticks	Strength, durable, last longer is good			1	10
3	Cutter		Steel	Machined and assemble d	Durable, good strength			2	25
4	Press with handle		Rubber Wood	Injection molding handle, wooden board	Hard, finishing well			1	15
5	Folding template		Plastic sheet	Folding the paper by keeping on the template	Informative			1	60

5.4.8. Usability audit of Product B Envelope maker developed in the lab

Table 5.31: Usability audit developed in the lab or envelope maker

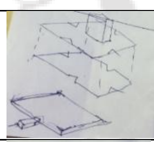
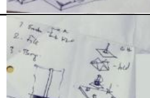
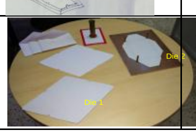
Parameter	**Details**	**Remarks/Problems**
Product Identification	**Product B lab** made envelope maker	
User Identification		Any one above age 15 can use this
Environment	Workspace Work surface	1. It can be used anywhere
Effectiveness to use Functional	Features Limitation Consequences	1. Effective, standard sized envelope can be done. 2. Required size and paper should be selected with prior cut. 3. The board should be kept on a flat and firm base.
Efficiency to use (Efficient)	Usable	Good ratings are given by the specific users.
Error free in use (Safe)	Safety	1. Confusion in holding the paper as it looks same from all angles. 2. The cutter may hurt the user. 3. One has to be careful while cutting the paper.

		4. Different dies are required for different size and shape envelopes.
Easy to use	User-friendly	1. Easy to use, anyone can operate easily, kids can use it under adult supervision. 2. No need of training or manual.
Enjoyable in use (Pleasurable)	User Experience	Feels good while using, Cost is low for individual user.

For further development of concepts and selection of the generated concept, we use the developed framework as shown below.

Based on the concept selection matrix, we will finalize the envelope maker based on the rankings as represented in Table 5.32. The steps involved and framework development is discussed in chapter 4. The designs of the envelope maker are subjected to evaluation using the proposed matrix frame work by the authors and is shown in the table below.

Table 5.32: Concept Selection Matrix frame work

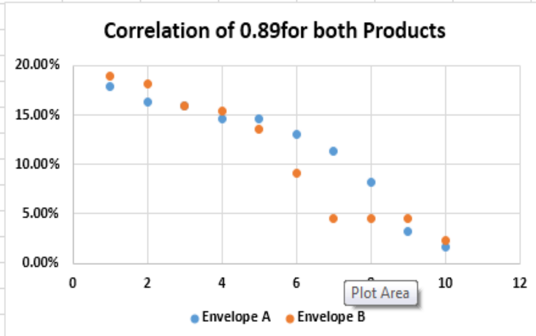
		Design Methods Applied	Degree of newness		Design Criteria (strong=9; medium=3; weak=1)								Sheer Innovation Prospect	Rank
				Criterion weightage	**9**	**9**	**9**	**9**	**3**	**9**	**3**	**3**		
Problem 1: Paper envelopes for differently abled people					**Low Cost**	**Light Weight**	**Efficiency**	**Functionality**	**Good ergonomics**	**Ease of use**	**Maintenance**	**Less process time**		
Case 1														
Design1		**Brain storming**	**1**		**3**	**1**	**1**	**1**	**1**	**3**	**3**	**9**	**120*1**	**4**
Design 2		**SCAMPER**	**1**		**3**	**3**	**3**	**3**	**1**	**3**	**3**	**3**	**156*1**	**3**
Design 3		**SCAMPER**	**3**		**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**486*3**	**2**
Collaborative		**Lean Design thinking**	**3**		**3**	**9**	**9**	**9**	**3**	**3**	**1**	**3**	**954*3**	**1**

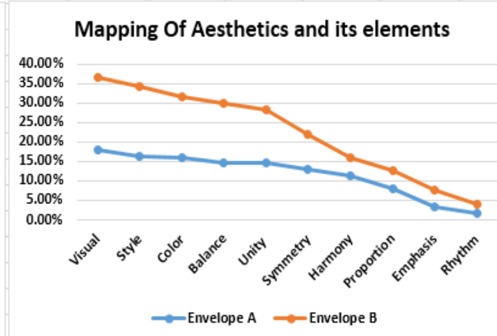
From the above Table 5.32, the collaborative design ranking is high, hence this design was finalized. The same design was delivered and a formal review was carried out with the same users. From this we could conclude that this was more effective and user friendly.

5.4.9. Based on prioritization of design elements for envelope makers, correlation, mapping and trends

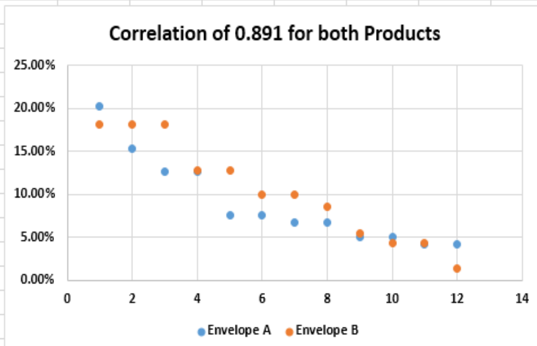
Envelope A and B correlation and mapping results

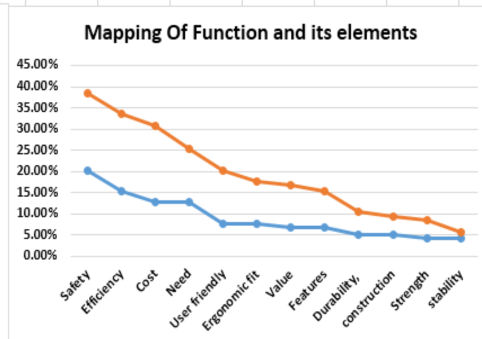
Aesthetics	Envelope A	Envelope B
Visual	17.89%	18.89%
Style	16.30%	18.16%
Color	15.89%	15.89%
Balance	14.67%	15.35%
Unity	14.67%	13.62%
Symmetry	13.04%	9.08%
Harmony	11.41%	4.54%
Proportion	8.15%	4.54%
Emphasis	3.26%	4.54%
Rhythm	1.63%	2.27%
	0.893916115	



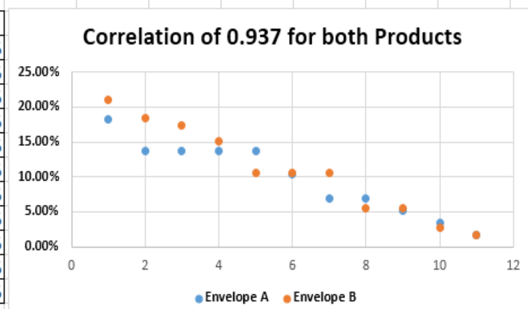


Function	Envelope A	Envelope B
Safety	20.32%	18.20%
Efficiency	15.28%	18.20%
Cost	12.67%	18.20%
Need	12.67%	12.78%
User friend	7.56%	12.78%
Ergonomic	7.56%	9.94%
Value	6.72%	9.94%
Features	6.72%	8.52%
Durability,	5.04%	5.48%
constructio	5.04%	4.26%
Strength	4.22%	4.26%
stability	4.22%	1.42%
	0.891800806	





Ergonomics	Envelope A	Envelope B
Safety	18.20%	21.04%
Efficiency	13.70%	18.41%
Reachabilit	13.70%	17.30%
Visibility	13.70%	15.03%
Force	13.70%	10.52%
Duration	10.32%	10.52%
Repetition	6.88%	10.52%
posture	6.88%	5.48%
Anthropom	5.16%	5.48%
Direction	3.44%	2.63%
Glance	1.72%	1.72%
	0.937808383	



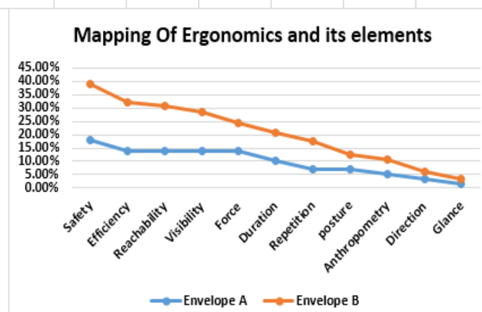


Figure 5.48: Aesthetics, function and ergonomics correlation and regression results and their trends

A correlation and regression analysis was computed for envelope makers (Pearson product-moment correlation coefficient) to assess the trends of design elements (Prioritized) and their weights for both the products. There was a positive correlation between all the prioritized design elements r=0.89, n=10, p=0.000487 for Aesthetics and its elements, r=0.937, n=11, p=1.99E-5 for ergonomics and its elements and for function and its elements, r=0.891, n=12, p=9.71E-5.
Overall, there was a strong, positive correlation between prioritized design elements for both the products. These rankings and weights can be utilized precisely in the designing phase. Similar trends were observed after mapping all the elements.

5.4.10. Linkographs developed for envelope maker Chinese made A and lab developed B

Aesthetics A and B

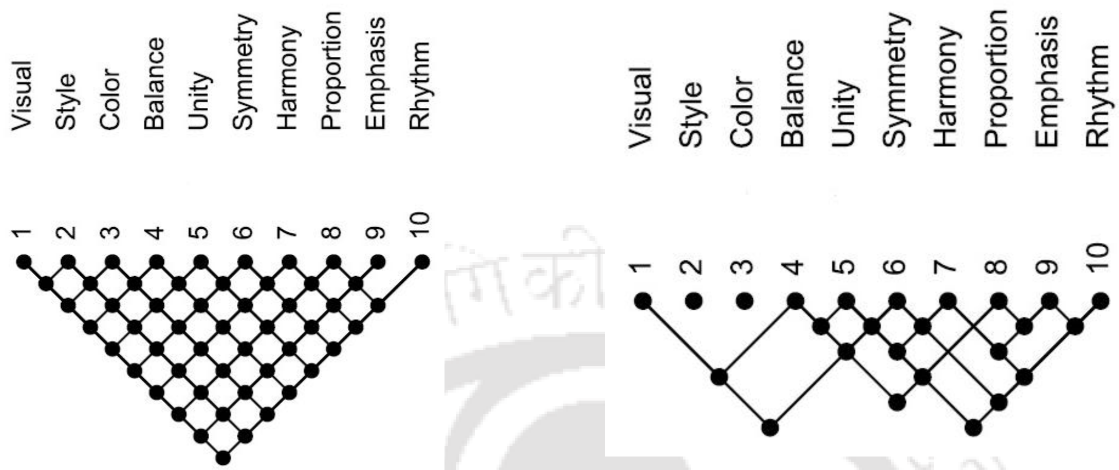


Figure 5.49: Linkographs for envelope maker Chinese made and lab developed for aesthetics and its elements

Aesthetics of the Product A, Chinese made envelope maker

N 0	LI	%CM3	%CM 4	%CM5	%CM6	%CM7	%CM8	%CM9
10 45	4.5	0.2	0.1	0.22	0.3	0.2	0.2	0.1

Aesthetics of Product B developed in-house

N 0	LI	%CM3	%CM 4	%CM5
10 15	1.5	0.2	0.2	-

Ergonomics A and B

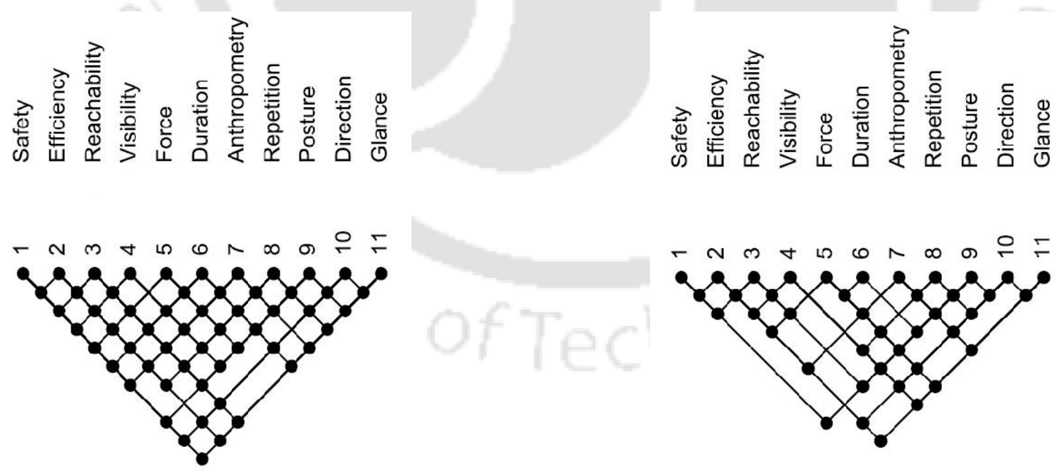


Figure 5.50: Linkographs for envelope maker Chinese made and lab developed for ergonomics and its elements

Ergonomics of Product A Chinese made envelope maker

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	%CM10
11 49	4.45	0.36	.09	0.27	0.09	0.27	0.27	-	0.1

Ergonomics of Product B developed in-house envelope maker

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7
11 31	2.81	0.27	0.18	0.09	0.27	0.09

Function A and B

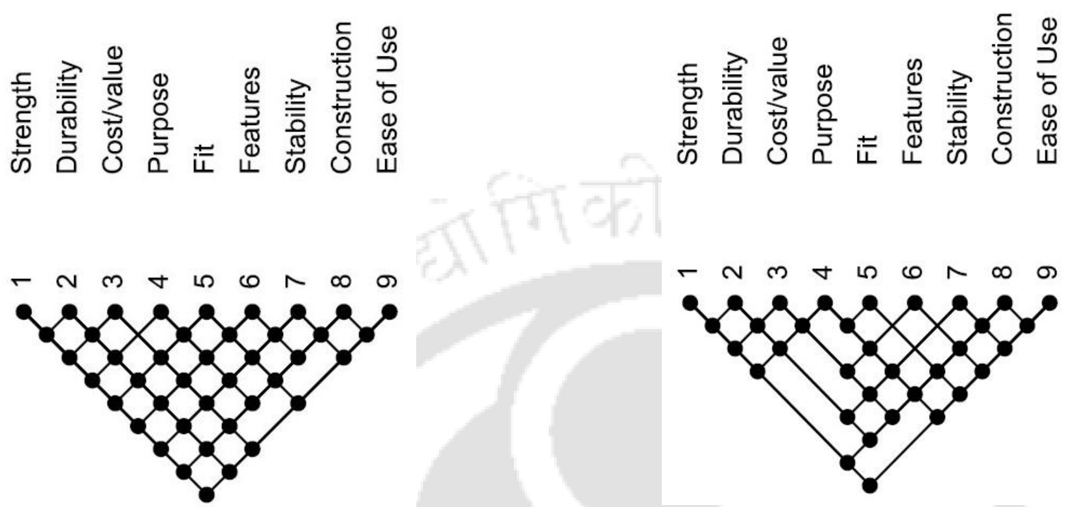


Figure 5.51: Linkographs for envelope maker Chinese made and lab developed for function and its elements

Function of Product A Chinese made envelope maker

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
9 33	3.66	-	0.33	0.22	0.22	0.22	0.11

Function product B developed in-house envelope maker

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7
9 25	2.7	0.11	0.22	0.22	-	0.22

Processes A and B

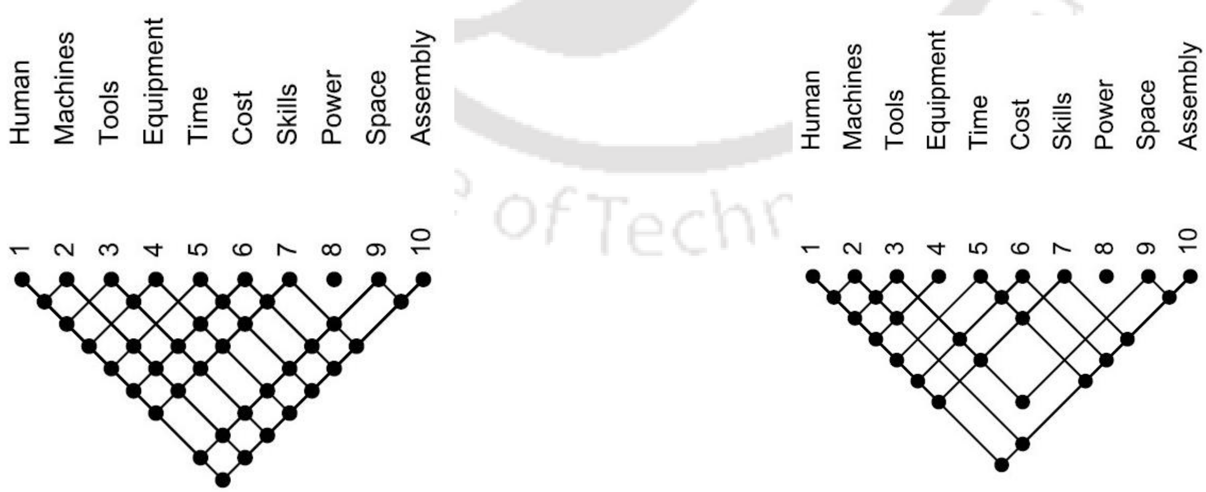


Figure 5.52: Linkographs for envelope maker Chinese made and lab developed for processes and its elements

Processes/Manufacturing Chinese made envelope maker

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
10 32	3.2	0.1	0.2	0.3	0.1	0.1	0.2

Processes/Manufacturing of product B developed in-house

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7
10 19	1.9	0.4	-	-	0.1	0.7

Operations Chinese made envelope maker

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
9 30	3.33	0.22	0.11	0.22	0.33	0.22	-

Operations for the device developed in-house envelope maker

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7
9 22	2.4	.11	.22	.33	.11	-

Usability Chinese made envelope maker

N 0	LI	%CM3	%CM4	%CM5
6 15	2.5	0.33	0.33	0.33

Usability of device developed in-house envelope maker

N 0	LI	%CM3	%CM4	%CM5
6 7	1.16	.16	-	.16

Operations A and B

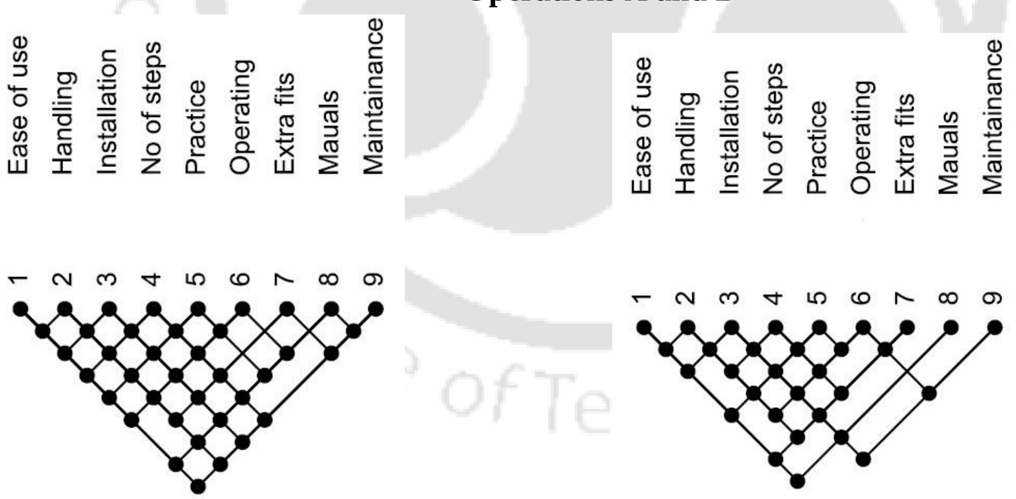


Figure 5.53: Linkographs for envelope maker Chinese made and lab developed for operations and its elements

Usability A and B

Figure 5.54: Linkographs for envelope maker Chinese made and lab developed for usability and its elements

Combined AEF of A and B

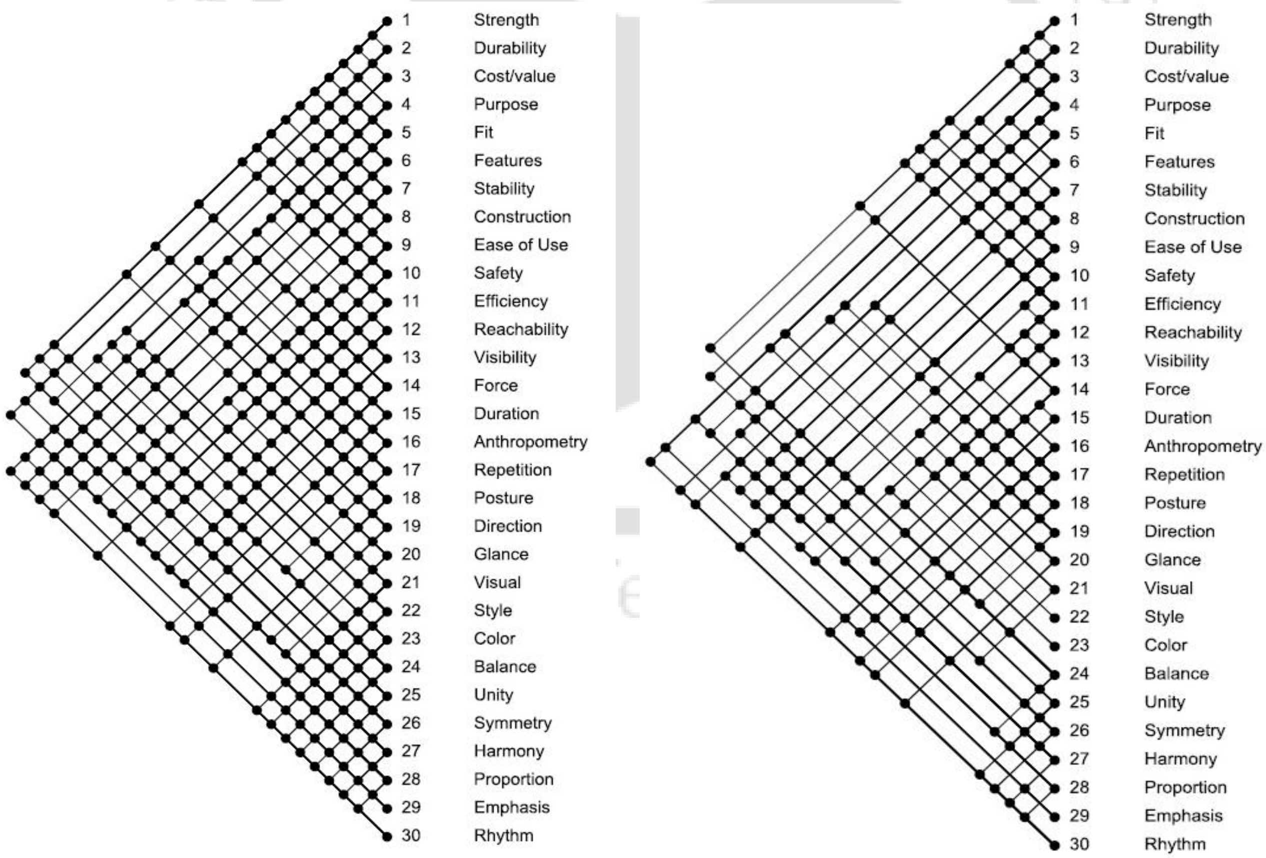


Figure 5.55: Combined linkographs for envelope maker Chinese made and lab developed for AEF

Combined UPO of A and B

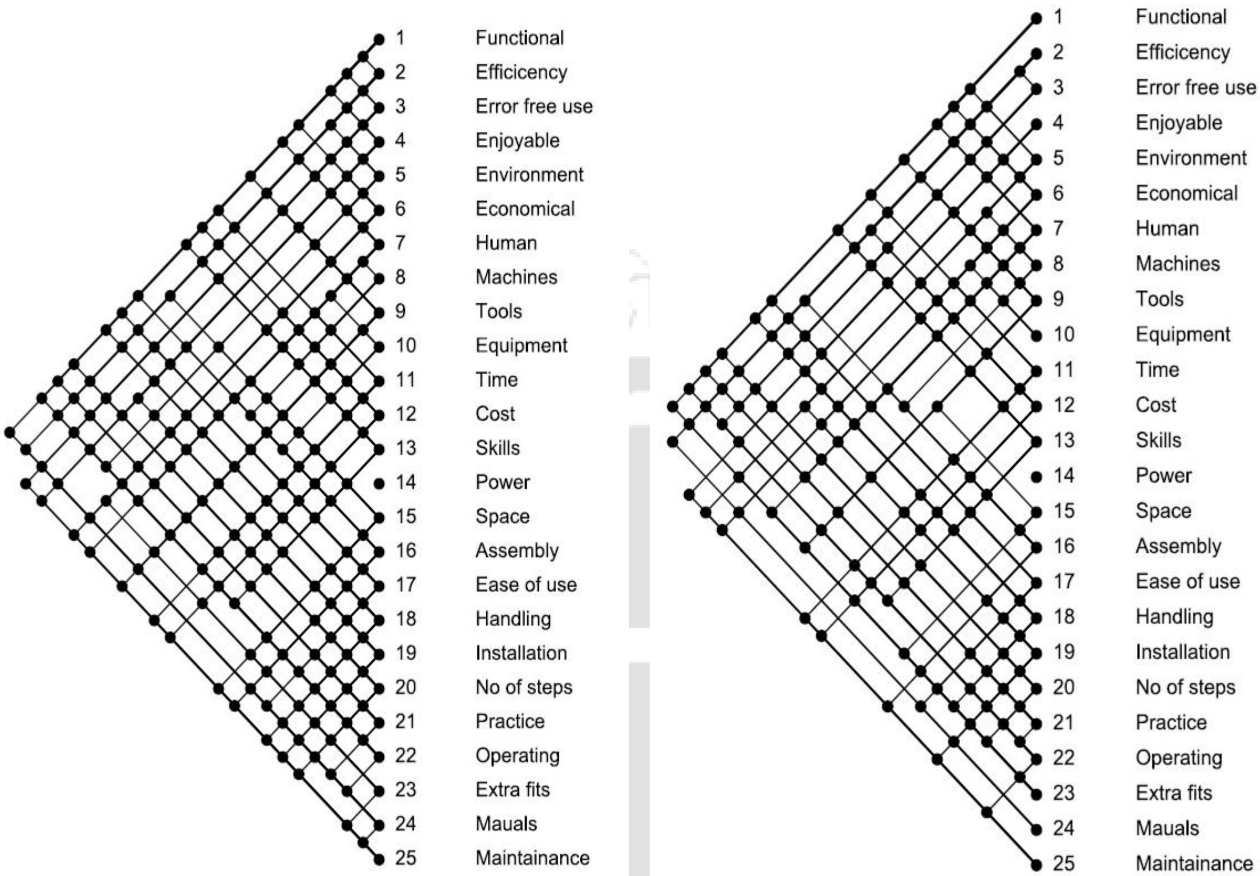


Figure 5.56: Linkographs for envelope maker Chinese made and lab developed for UPO

5.4.11. Consolidated findings

Overall results of the developed linkographs **(**Envelope A-Chinese made, Envelope B-made in the lab)

Table 4.33: Consolidated results of linkographs generated

	No of Moves N	Link Index LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	
Envelope A	9	4.5	0.2	0.1	0.2	0.3	0.2	0.2	0.1	Aesthetics
Envelope B	9	1.5	0.2	0.2						
Envelope A	11	4.45	0.36	0.09	0.27	0.09	0.27	0.27		Ergonomics
Envelope B	11	2.81	0.27	0.18	0.09	0.27	0.09			
Envelope A	10	3.66		0.33	0.22	0.22	0.22	0.11		Function
Envelope B	10	2.7	0.11	0.22	0.22		0.22			

Envelope A	10	3.33	0.22	0.11	0.22	0.33	0.22			Operations
Envelope B	10	2.4	0.11	0.22	0.33	0.11				
Envelope A	10	3.2	0.1	0.2	0.3	0.1	0.1	0.2		Processes
Envelope B	10	1.9	0.4			0.1	0.7			
Envelope A	6	2.5	0.33	0.33	0.33					Usability
Envelope B	6	1.16	0.16		0.16					

Hence, from the above table we conclude that Envelope A, link index is 4.5 and Envelope B is 1.5, the difference between the link index is the relative innovation index. Envelope A is more value added than the Envelope B, or Envelope A has index of 3 making it innovative than Envelope B in aesthetics. Similarly, Envelope A has index of 1.64 making it innovative than Envelope B ergonomically, functionally Envelope A is 0.96 index more than Envelope B and Operations wise the Envelope A is 0.93 index more innovative. The usability has index 1.34 and processes wise 1.3 value added than the Envelope B. By observing all the results of individual design elements, Envelope A maker i.e. the Chinese envelope maker has higher values. Hence, making it more innovative than the Envelope B.

Combined AEF results

Table 5.34: Combined results of aesthetics, ergonomics and function

	LI	%CM3	%CM 4	%CM 5	%CM 6	%CM 7	%CM 8	%CM 9	%CM 10	%CM 11	%CM 12	%CM 13	%CM 14	%CM 15	%CM 16	%CM 17	%CM 18	%CM 19	%CM 20
Envelope A	9.16	0.1	0.06	0.16	0.13	0.13	0.13	0.33	0.03	0.06	0.16	0.16	-	0.06	0.3	0.01	-	0.01	0.01
Envelope B	5.1	0.06	0.1	0.16	0.1	0.23	0.06	0.23	0.13	-	0.03	0.03	-	0.03	-				

Combined UPO results

Table 5.35: Combined results of usability, processes and operations

	LI	%CM3	%CM 4	%CM 5	%CM 6	%CM 7	%CM 8	%CM 9	%CM 10	%CM 11	%CM 12	%CM 13	%CM 14	%CM 15	%CM 16	%CM 17	%CM 18	%CM 19	%CM 20
Envelope A	7.28	0.04	0.12	0.12	0.2	0.12	0.16	-	0.12	0.16	0.16	0.12	0.04	0.04	0.04	0.04	0.04	-	0.04
Envelope B	5.32	0.24	0.08	0.12	0.16	0.16	0.2	.08	0.12	0.04	0.08	0.08	-	0.04	-	0.24	0.08	0.12	0.16

When all the design elements such as aesthetics, ergonomics and function are combined the link index Envelope A is higher i.e. 9.16. And in case of usability, operations and processes the envelope A has a value of 7.28. Therefore, making it more value-added product.

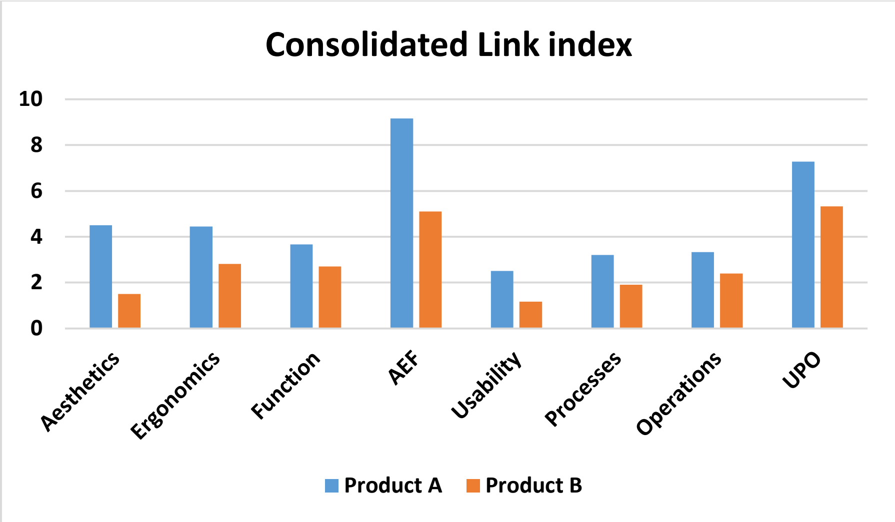


Figure 5.57: Link index for both envelope makers

The Fig. 5.57 shows that the individual and combined link index of design elements for both the products. The above graph clearly indicates that the link index of product A is higher in all aspects and it is more value added than the one developed in-house.

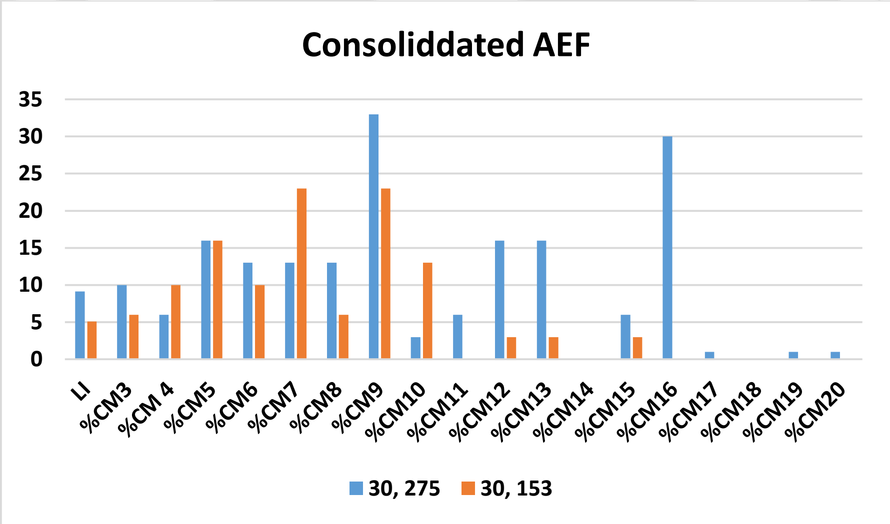


Figure 5.58: Consolidated % CMs for both envelope makers, AEF

Fig. 5.58 shows the percentage critical moves in terms of aesthetics, ergonomics and function for all the products. The above graph, indicates the link index of both products along with % critical moves indicating the depth of the relations built and granularity of the analysis.

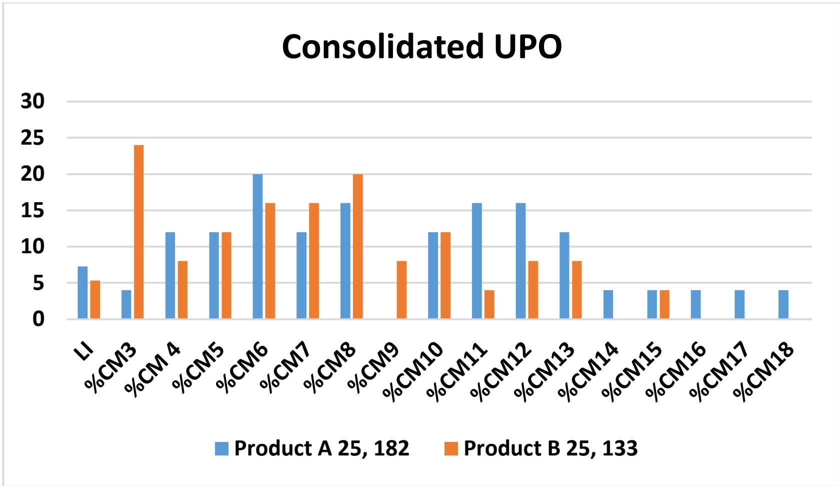


Figure 5.59: Consolidated %CMs for both envelope makers, UPO

Fig. 5.59 shows % critical moves in terms of usability, processes and operations for both the products. The above tables and graphs indicate the link index of both products along with % critical moves indicating the depth of the relations built and granularity of the analysis.

5.5 Case study 4-Product 4, Computing devices

5.5.1. Vidyut laptop A and Akash tablet B

Figure 5.60: Showing images of Vidyut laptop and Akash Tablet

The products adopted for research studies, are products of IIT Bombay (Akash tablet) and belong to the same family and perform the same function. The Akash tablet was designed initially to find applications in the field of education. However, the advanced version of the same was Vidyut Laptop (Other firm). The User studies have proved that the latter is complicated to use - technically termed as market myopia. It is a concept where, a designer tries to innovate and modify the product to make it more suitable for use, but eventually ends up making the product more complicated to use and does not find an acceptance by the user. The countries like China and Hong Kong are known for innovations in electronic segment over the past few decades, as they have adopted automated assembly lines and technology with minimal human intervention, which reduces the cost of production. At the other end, Indian MSMEs have failed to achieve success in this field, as our manufacturing units still follow age old traditional methods and norms in designing. Hence the above study has been initiated to get insights into design applications which are affordable and sustainable. The study involves mapping of MSME's, technological advances adopted in manufacturing and levels of innovation adopted. The research outcomes will help the designers and manufacturers to add more value to the product and yet make it more cost effective.

Vidyut Laptop is one such example as it adopts a backward integration technique, wherein the resource and technology available to design the product was used. And, the other components and parts like outer shell, mouse and charger, which added to the cost of product were outsourced from countries like China. The question pertaining to the extent of value addition, levels of innovation adoption and adopting outsourcing strategies have been answered through the analysis. The process adopted to evaluate and analyze is as follows: design audit, product analysis and linkographs to identify the relative innovation index between the products.

In the entire process of research and innovation, one should not forget to do a segment profiling and country profiling, since cultural dimensions of value and utility vary from country to country. Compared to countries like the United States and the United Kingdom, India has no standardized defined criteria and specification for sale of electronic goods. Since the volatile market conditions give the innovators an extra mileage to innovate, one should make use of this opportunity to explore and flourish.

Post evaluation we can say that the major difference between the products under study is that the laptop is just an extended version of the tablet, with components such as hinge, keyboard, mouse, and casing being added which convert the tablet into a laptop. Hence, it finds the applications in the field of education as the product is affordable to the students. Therefore, we can say that innovation is doing the existing things in a new way.

5.5.2. Specification of Akash Tablet

Table 5.36: Features of Akash tablet

Display	800 × 480 resolution, 7 in (18 cm) diagonal
Processor	ARM11, 366 MHz
Memory	Expandable up to 32GB, external hard disk drives up to 2GB
Battery	2100 mAh
Camera	Standard VGA front
Weight	350 g
Connectivity	Bluetooth, Wi-Fi, mic-in, speaker-out
Price	Rs. 2000/-

Specification of Vidyut laptop

Table 5.37: Specification of Vidyut laptop

Display	10-inch, 1024x680 resolution
Processor	1 GHz dual Core ARM v7
Memory	1 GHz dual Core ARM v7**:** 1GB RAM, 8GB NAND Flash storage, expandable up to 32GB, external hard disk drive up to 2GB
Battery	5000 mAh
Camera	Standard VGA front
Weight	1 kg
Connectivity	Bluetooth, Wi-Fi, 2xUSB 2.0, mini HDMI, Ethernet LAN, mic-in, speaker-out
Price	Rs. 8,499/-

Table 5.38: Product features of Akash tablet

WIFI 802.11 b/g/n	**Bluetooth Version 3.0 class 2 or better**	**Ethernet LAN RJ45 port**	**Battery 5000 mAh**	**Front camera VGA 0.3 MP for video calls**
Processor Dual Core, 1.5 GHz	**GB RAM**	**32GB SD Card Slot**	**2 USB support**	**Touch pad**

Though this laptop is of high technology product from the manufacturing point of view, Taiwan, China and Japan can do it easily as they have adopted full automatic assembly lines. In case of India we are still utilizing man power to do the assembly and other works, which makes the cost of manufacturing high if manufactured in India. Hence, the cost cannot be brought down in comparison to other countries.

We can state that to manufacture such technological products we require automation so that we can compete in the market w.r.t cost of the product. To overcome this, MSMEs can adopt a method of outsourcing i.e., to design a product, outsource all the parts and bring it together. The value addition starts with the designing of the product, assembling and cost. Here the designing of the product starts with the need of the users, availability of the resources in terms of components. This is followed by product design and manufacture by outsourcing and it is a way of backward design. In such products, the maximum value addition converts to maximum innovation.

In this case, Akash tablet extension version is the Vidyut laptop. It is a classic case of doing the things in new way, i.e., the same company has seen the parts that are available, put together everything, outsourced the shell and assembled the product. This has added value in terms of function, aesthetics, usability and construction.

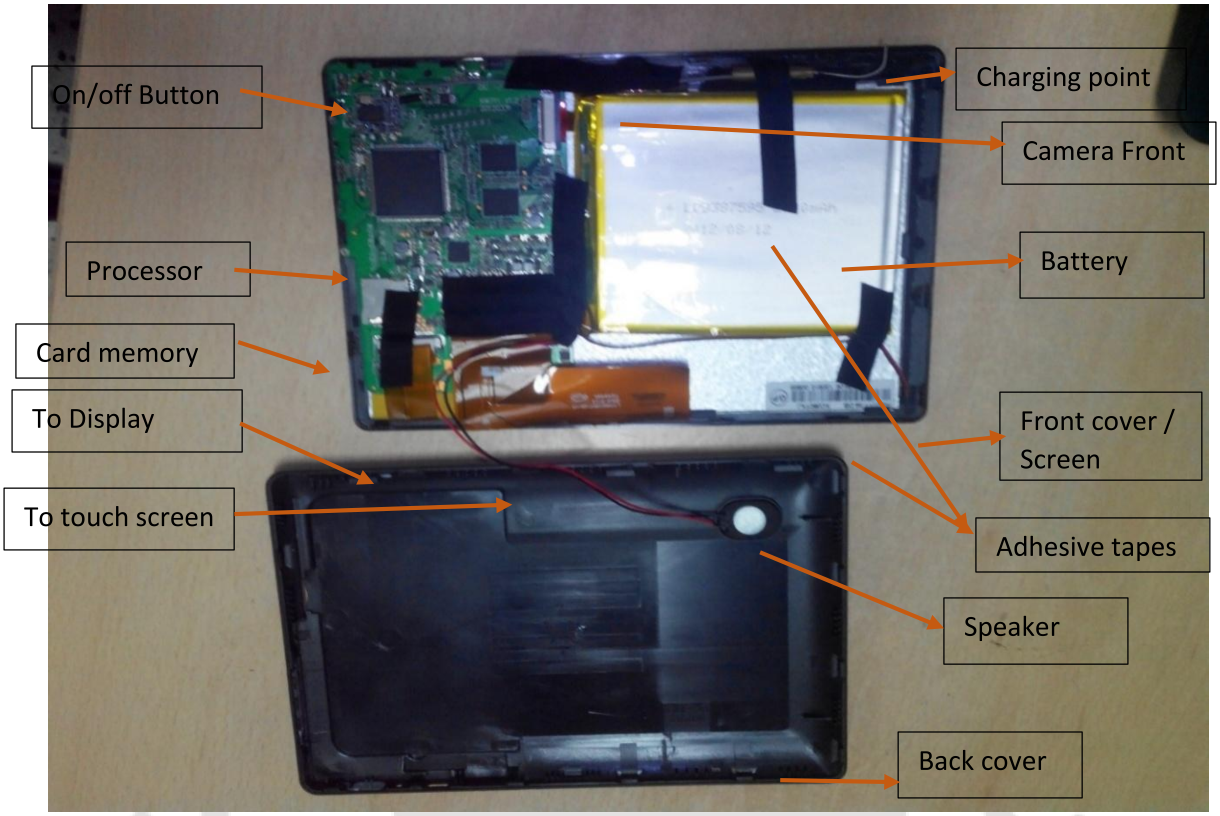


Figure 5.61: Akash tablet disassembled and its parts

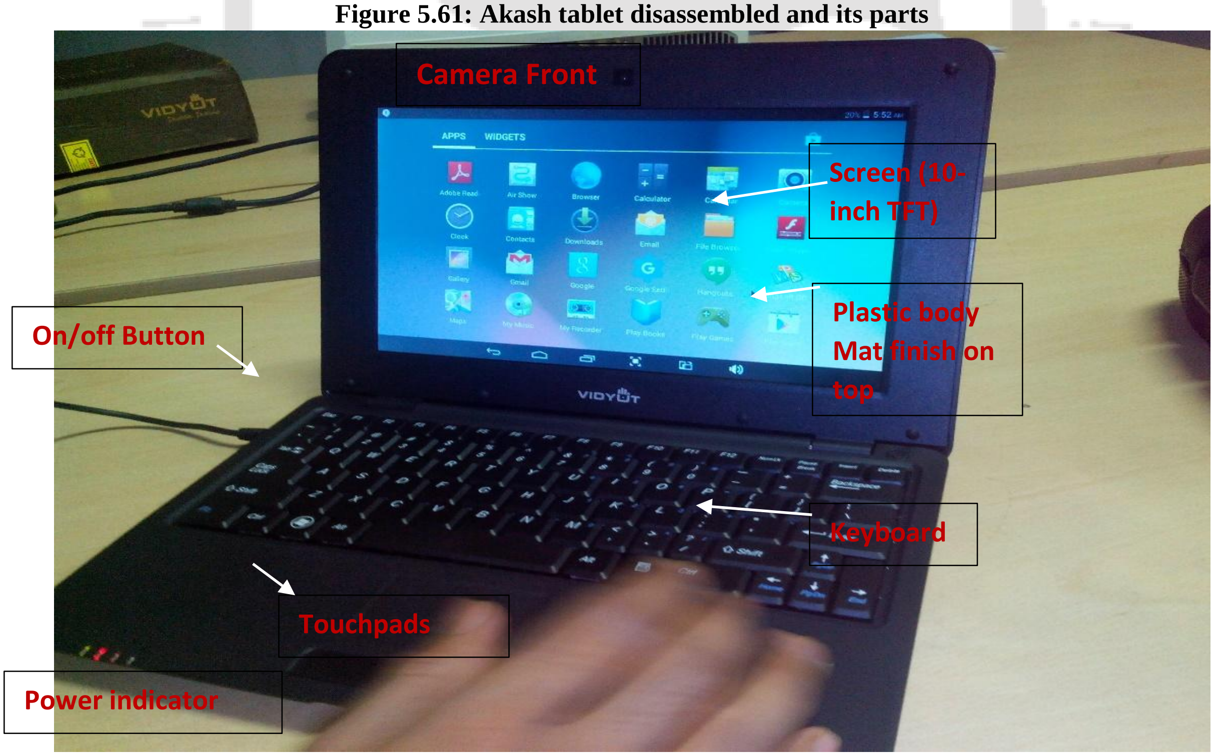


Figure 5.62: Product features of Vidyut laptop

Vidyut Laptop while working

Back

Back Cover (Plastic)

Figure 5.63: Vidyut laptop disassembled with its parts

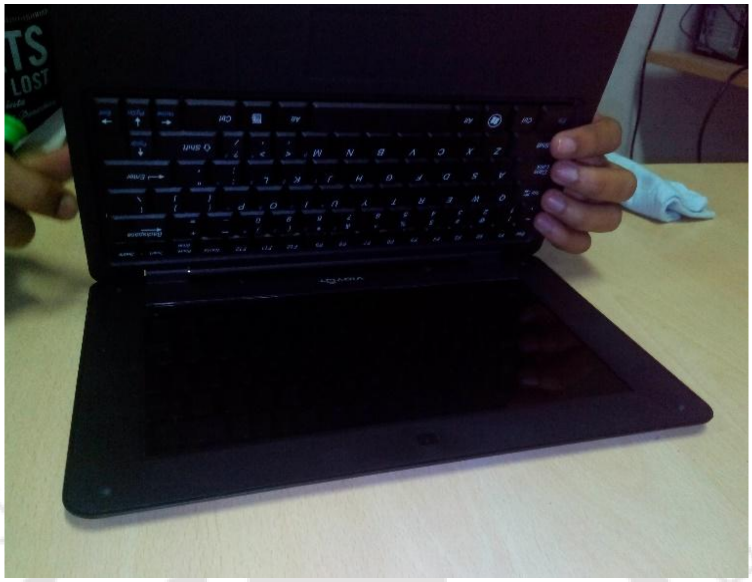


Figure 5.64: Vidyut laptop disassembled with its parts

5.5.3. Fish bone diagram of Akash Tablet

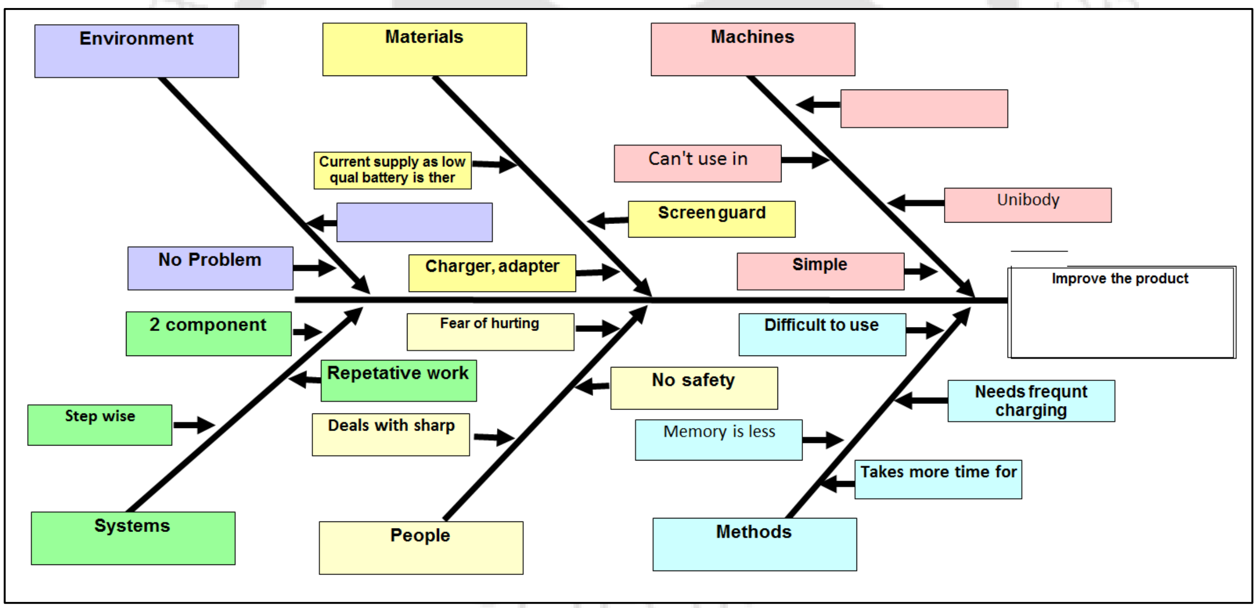


Figure 5.65: Fish bone diagram of Akash Tablet

5.5.4. Value engineering and Value analysis of the Akash Tablet

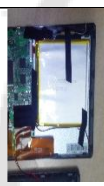
The actual cost of the Akash tablet is Rs. 2000/- after the calculations (approx. + mass production) it is Rs. 1407/- this is cost considered for our analysis.

Table 5.38: Value analysis/ Value engineering of Akash tablet

Sl. No.	No of Parts	Component	Function	Material	Importance to customer	Cost in Rs.	%	Need of alteration and reason	Priority of redesign
1	1	Processor	- Computation, Heart of the tablet	PCB	Medium	800	56.85	No	
2	1	Touch screen/Display	-Acts as display as well as a touch screen to operate	TFT	-High	200	14.21	No	
3	1	Camera Front	-To capture images, calling etc.	VGA	Medium	150	10.66	Yes, High resolution camera can be used	1
4	1	Battery	Supplies/stores the power for tablet	2100 mAh	Low	150	10.66	Yes, same price little higher battery can be used	1
5	1+1	Front/Back cover	Covers all the parts inside the front/back cover	Plastic	High	50	3.55	Yes, High quality plastic with higher finish can be used	2
6	1	Speaker	Sound enhancer	Assembly	Medium	20	1.4	High quality speaker can be used	3
7	1	On/Off button	Switch the tab on/off	Plastic	High	2	0.14	Yes, placement should be changed	6
8	6	Connection wires	Connecting all the parts in such way that it works without any flaws	Cu	Low	20	1.4	No	3
9	5 inches	Adhesive tape	Wires will be stick to individual parts	Adhesive	Low	5	0.35	No	5
10	1	Charger	USB charger	Plastic/ metal	Medium	10	0.71	Yes, size can be made still smaller	4

5.5.5. Engineering analysis of Akash tablet

Table 5.39: Engineering analysis of Akash tablet

Sl. No.	Component	Figures	Material	Process	Fixed costs	Variable costs	Volume	Total Unit Cost in Rs.
1	Processor		PCB	PCB, solder, connections	100	700	1	800
2	Touch screen/Display		TFT	Injection molding, etching process	20	180	1	200
3	Camera Front		VGA	Lens fitting in assembly	20	130	1	150
4	Battery		2100mAh	Li ion batteries	30	120	1	150
5	Front/Back cover		Plastic	Molding	10	40	1	50
6	Speaker		Assembly	Speaker assembly	5	15	1	20
7	On/Off button		Plastic	Pressed			1	2
8	Connection wires		Cu	Wire drawn and coating	3	17	6	20
9	Adhesive tape		Adhesive	Adhesives one side			5 inches	5

10	Charger		Plastic/metal	Molding and assembly			1	10

5.5.6. Usability Audit of Akash tablet

Table 5.40: Usability audit of Akash tablet

Parameter	**Details**	**Remarks/Problems**
Product Identification	Akash tablet	
User Identification		Any one above age 5 can use
Environment	Workspace Work surface	1. Can be used anywhere. 2. Not in direct sunlight.
Effectiveness to use (Functional)	Features Limitation Consequences	1. Not 100% effective. More attention is needed. 2. Difficulty in using as the touch is not that sensitive. 3. Needs proper design of the outer body. 4. Key board and mouse can be attached. 5. Mini laptop can be made. 6. Power back up can be increased.
Efficiency to use (Efficient)	Usable	Above average ratings given by the variety of customers and users for this price range.
Error free in use (Safe)	Safety	1. Fear of falling, can be eliminated by providing proper casing. 2. Typing is difficult as the keyboard is missing. 3. Confusion in holding as it looks same from all angles. 4. Touch, sharpness, pixels should be improved.
Easy to use	User-friendly	1. Easy to use, anyone can operate easily, kids can use it under adult supervision. 2. No need of training or manual. 3. All parts are covered.
Enjoyable in use (Pleasurable)	User Experience	Not up to the mark in comparison with other tablets. Feels good to own a tablet at a lower price.

5.5.7. Usability audit of Vidyut laptop

Table 5.41: Usability audit of Vidyut laptop

Parameter	**Details**	**Remarks/Problems**
Product Identification	Vidyut laptop	

User Identification		Any one above age 5 can use it
Environment	Workspace Work surface	1. Can be used anywhere. 2. Not in direct sunlight.
Effectiveness to use (Functional)	Features Limitation Consequences	1.100% effective. 2. Difficulty in using it as the keyboard is small. 3. Needs proper design of the outer body (Sturdy). 4. Key board and mouse are very small and of low quality. 5. It is a lower version of mini laptop. 6. It does not have a decent backup as the battery discharges quickly.
Efficiency to use (Efficient)	Usable	Above average ratings given by the variety of customers and users for this price range.
Error free in use (Safe)	Safety	1. Fear of falling can be eliminated by providing a strong casing. 2. Typing is difficult as the keyboard is small. 3. Touch, sharpness, pixels should be improved.
Easy to use (Friendly)	User-friendly	1. Easy to use, anyone can operate easily, kids can use under adult supervision. 2. No need of training or manual. 3. All parts are covered.
Enjoyable in use (Pleasurable)	User Experience	Not up to the mark in comparison with other high end laptops. Feels good to own a tablet at a lower price.

5.5.8. Linkograph developed and results are Vidyut laptop and Akash tablet

For Aesthetics

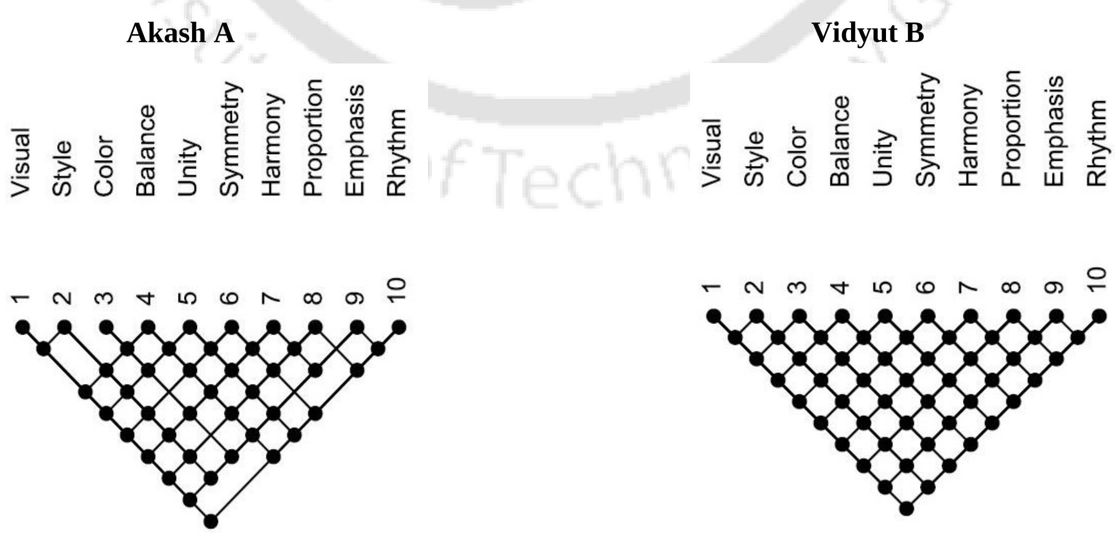


Figure 5.66: Linkographs for Vidyut laptop and Akash tablet aesthetics and its elements

Aesthetics

Product A

N	0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
10	36	3.6	0.2	0.3	0.2	0.4	0.1	0.1

Aesthetics

Product B

N	0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9
10	44	4.4	0.2	0.3	0.1	0.2	0.3	0.1	0.09

For Ergonomics

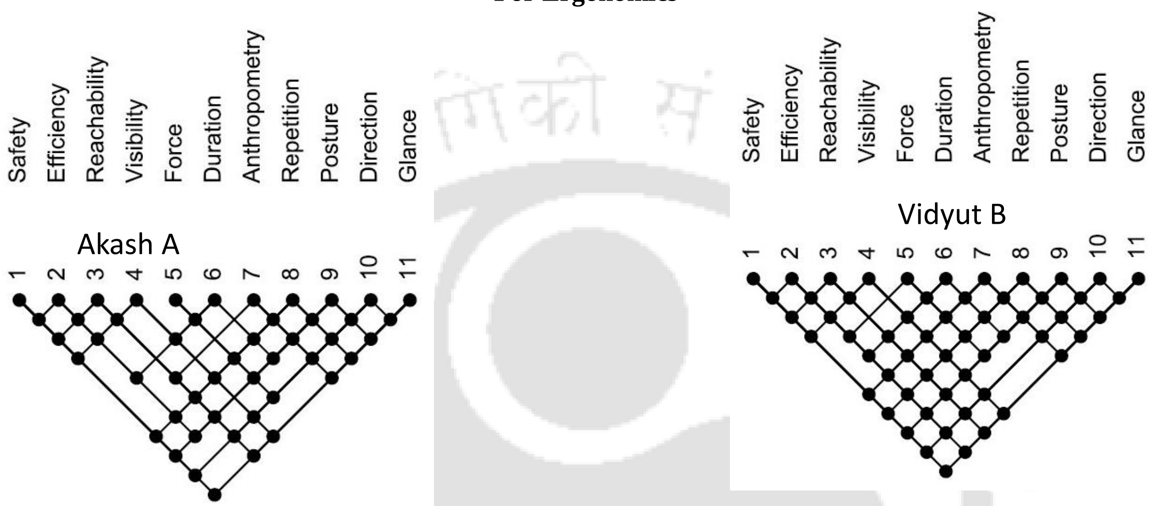


Figure 5.67: Linkographs for Vidyut laptop and Akash tablet ergonomics and its elements

Product A

N	0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
11	38	3.45	0.27	0.27	0.09	0.09	0.45	-

Product B

N	0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9
11	47	4.27	0.27	0.27	-	0.18	0.27	0.27	0.09

For Function

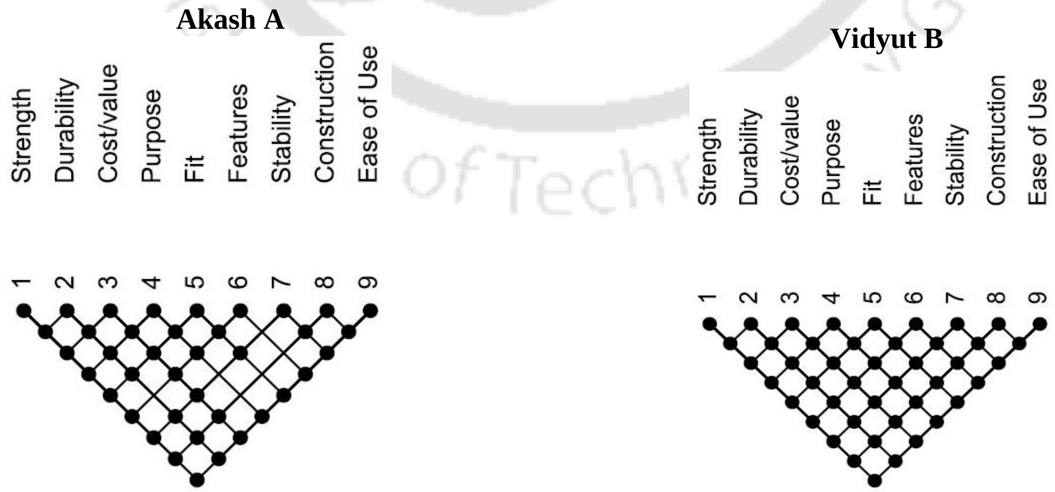


Figure 5.68: Linkographs for Vidyut laptop and Akash tablet function and its elements

Product A

N	0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
9	30	3.33	0.33	0.44	-	0.22	-	0.22

Product B

N	0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
9	36	4	0.22	0.22	0.22	0.22	0.22	0.22

For Processes

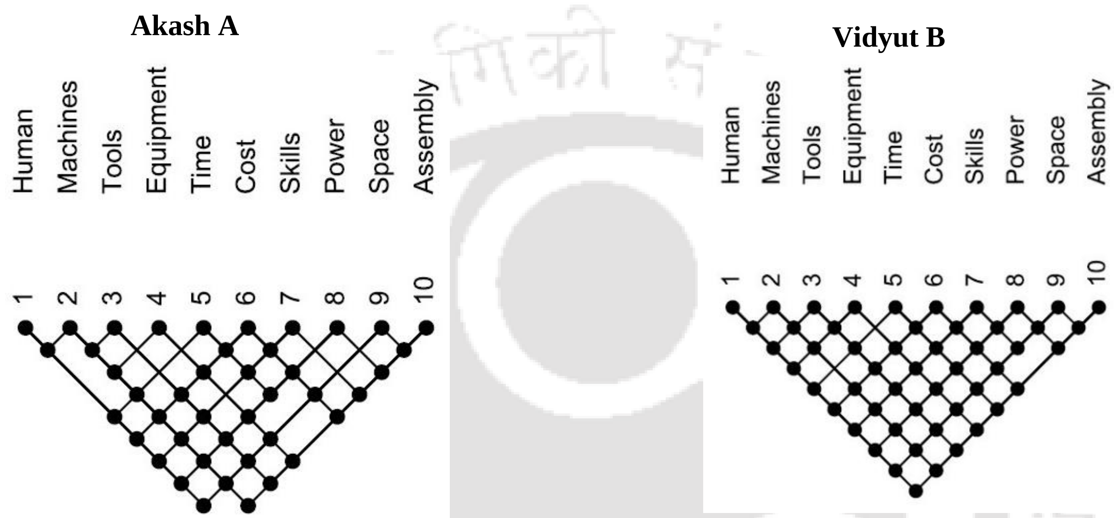


Figure 5.69: Linkographs for Vidyut laptop and Akash tablet processes and its elements

Product A

N	0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
10	24	2.66	0.11	0.22	0.44	0.22	0.11	0.11

Product B

N	0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9
10	42	4.2	0.1	0.1	0.3	0.1	0.3	0.2	0.1

For Operations

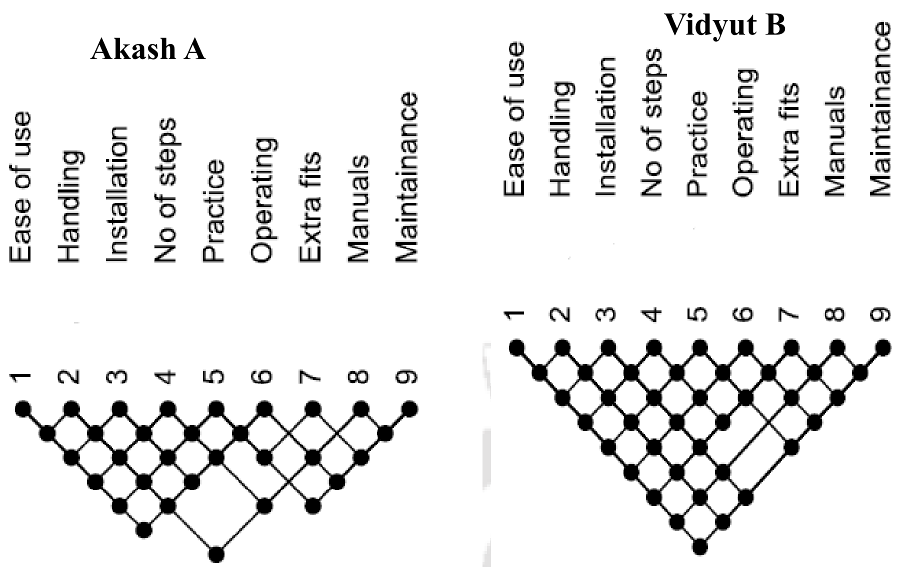


Figure 5.70: Linkographs for Vidyut laptop and Akash tablet operations and its elements

Product A

N 0	LI	%CM3	%CM4	%CM5	%CM6
9 24	2.66	0.22	0.44	0.44	-

Product B

N 0	LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8
9 33	3.66	0.44	0.11	0.22	0.22	0.22	0.11

For Usability

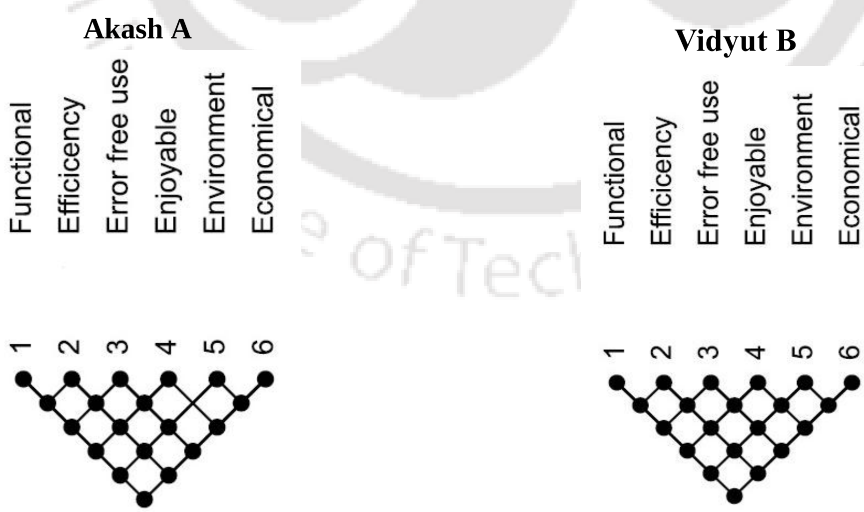


Figure 5.71: Linkographs for Vidyut laptop and Akash tablet usability and its elements

Product A

N 0	LI	%CM3	%CM4	%CM5
6 14	2.33	0.5	0.16	0.33

Product B

N 0	LI	%CM3	%CM4	%CM5
6 15	2.5	0.33	0.33	0.33

Combined AEF

Akash A **Vidyut B**

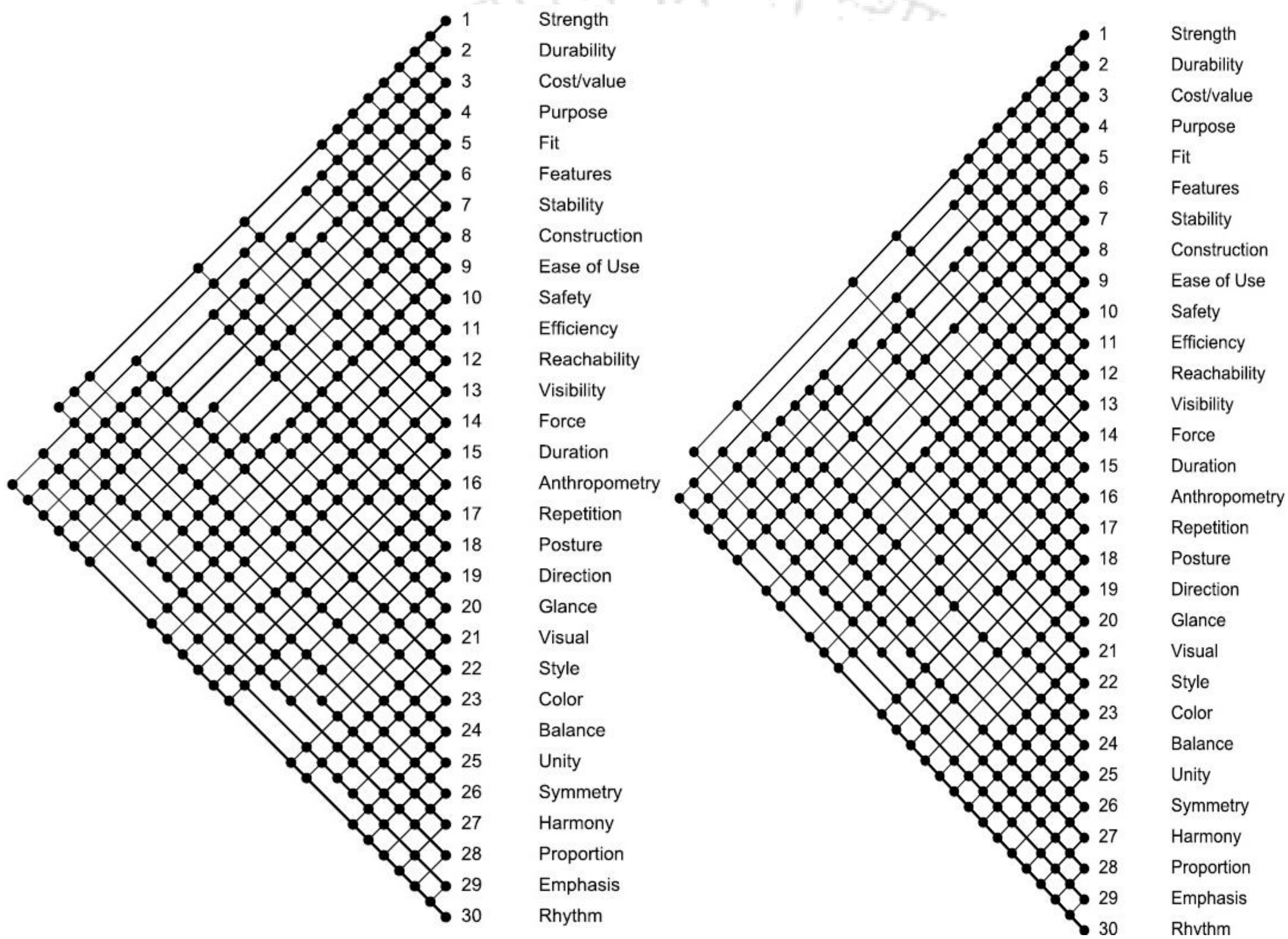


Figure 5.72: Combined linkographs for Vidyut laptop and Akash tablet AEF and its elements

Combined UPO

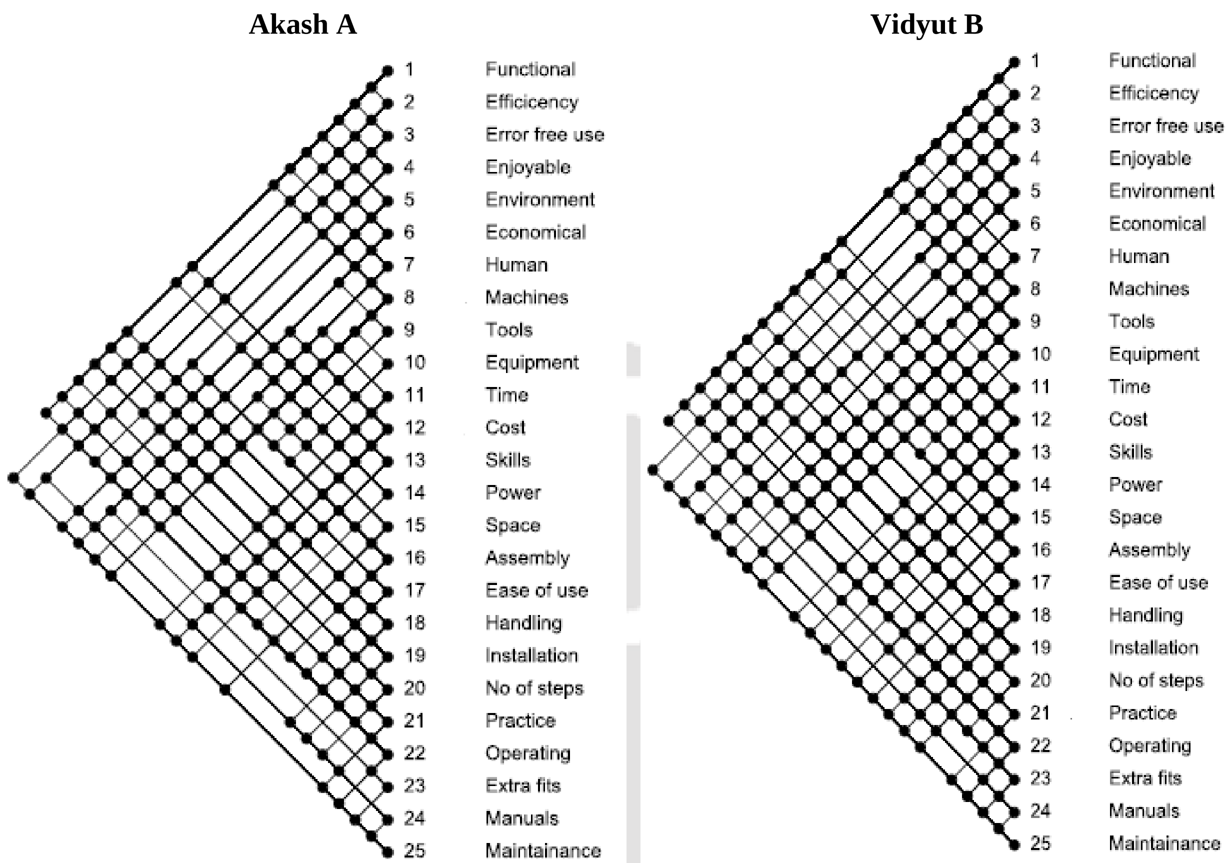


Figure 5.73: Combined linkographs for Vidyut laptop and Akash tablet UPO and its elements

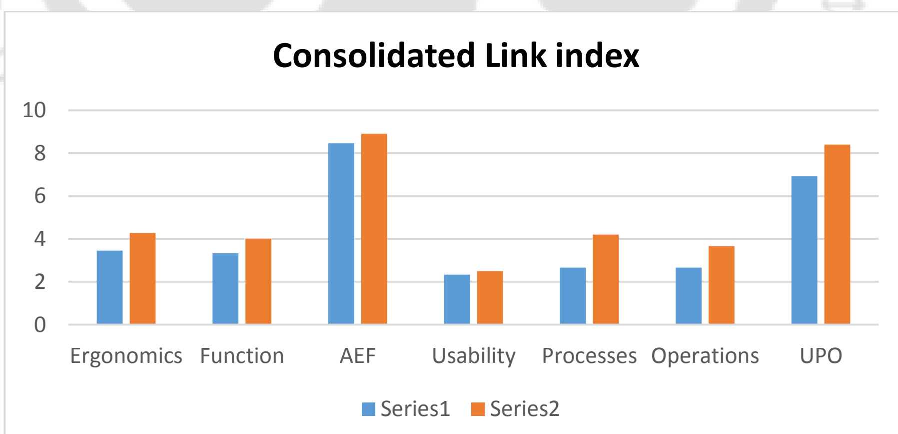


Figure 5.74: Consolidated Link index for both Tablet and Laptop

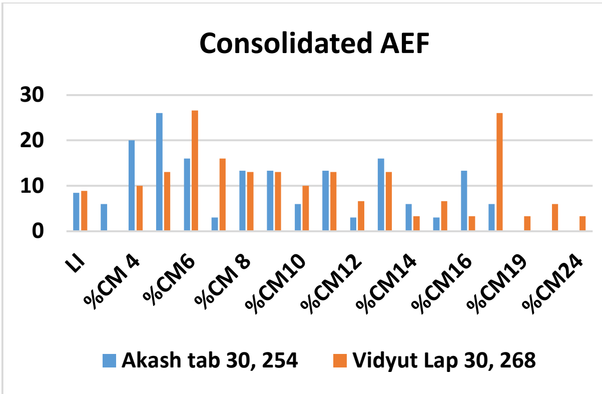


Figure 5.75: Consolidated %CMs for both Tablet and laptop, AEF

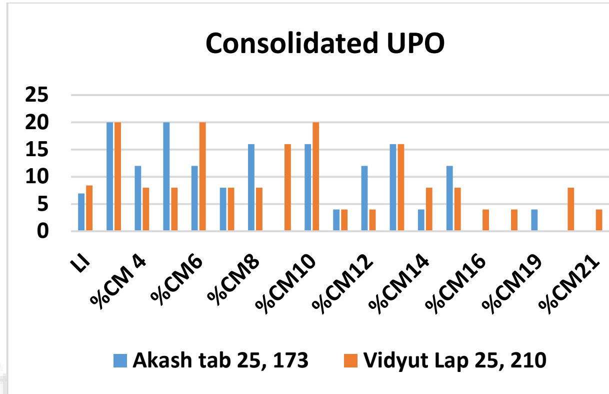


Figure 5.76: Consolidated %CMs for both Tablet and laptop, UPO

The Fig. 5.75 and 5.76 shows the percentage critical moves in terms of aesthetics, ergonomics, function, usability, operations and processes for both the products. From the above graph, the link index of both products are indicated along with percentage critical moves, indicating the depth of the relations built and granularity of the analysis.

5.5.9. Overall results of the developed linkographs

Table 5.42: Overall results of generated linkographs

	No of Moves N	Link Index LI	%CM3	%CM4	%CM5	%CM6	%CM7	%CM8	%CM9	
Akash	9	3.6	0.2	0.3	0.2	0.4	0.1	0.1		Aesthetics
Vidyut	9	4.4	0.2	0.3	0.1	0.2	0.3	0.1	0.8	
Akash	11	3.45	0.27	0.2	0.09	0.09	0.45			Ergonomics
Vidyut	11	4.27	0.27	0.27		0.18	0.27	0.27	0.09	
Akash	10	3.33	0.33	0.44		0.22		0.22		Function
Vidyut	10	4	0.22	0.22	0.22	0.22	0.22	0.22	0.22	
Akash	10	2.66	0.22	0.44	0.44					Operations
Vidyut	10	3.64	0.44	0.11	0.22	0.22	0.22	0.22	0.11	
Akash	10	2.66	0.11	0.22	0.44	0.22	0.11	0.11		Processes
Vidyut	10	4.2	0.1	0.1	0.3	0.1	0.3	0.2	0.1	
Akash	6	2.33	0.5	0.16	0.33					Usability
Vidyut	6	2.5	0.33	0.33	0.33					

Hence, from the above table we can conclude that Vidyut laptop B, link index is 4.4 and Akash tablet A is 3.6, the difference between the link index is the relative innovation index. Vidyut laptop B is more value added than the Akash tablet A. In a similar way ergonomically Vidyut laptop B is more innovative than Akash tablet A. Functionally Vidyut laptop B is better than Akash tablet.

Operations wise Vidyut laptop B is more innovative, usability wise and processes wise Vidyut laptop B is more value added than Akash tablet A. By observing all the results of individual design elements Vidyut laptop B has higher values. Hence, makes it more innovative than the Akash tablet A.

Combined AEF

Table 5.43: Combined aesthetics, ergonomics and function results

	LI	%CM3	%CM 4	%CM 5	%CM 6	%CM 7	%CM 8	%CM 9	%CM 10	%CM 11	%CM 12	%CM 13	%CM 14	%CM 15	%CM 16	%CM 17	%CM 18	%CM 19	%CM 20
Akash	8.46	.06	0.2	0.26	0.16	0.03	0.133	0.133	0.06	0.133	0.03	0.16	0.06	0.03	0.133	-	0.06	-	0.06
Vidyut	8.9	-	0.1	0.13	0.266	0.16	0.13	0.13	0.1	0.13	0.066	0.13	0.033	0.066	0.033	-	0.16	0.033	

Combined UPO

Table 5.44: Combined usability, processes and operations results

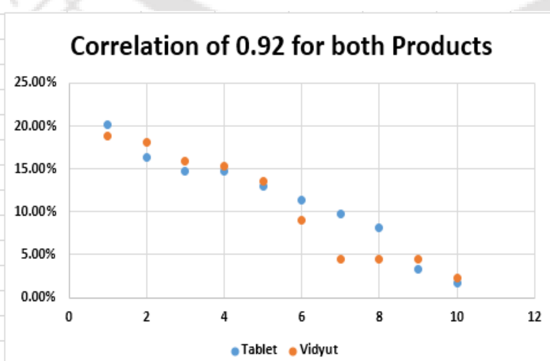
	LI	%CM3	%CM 4	%CM 5	%CM 6	%CM 7	%CM 8	%CM 9	%CM 10	%CM 11	%CM 12	%CM 13	%CM 14	%CM 15	%CM 16	%CM 17	%CM 18	%CM 19	%CM 20
Akash	6.92	.2	0.12	0.2	0.12	0.08	0.16	-	0.16	0.04	0.12	0.16	0.04	0.12	-	-	0.04	-	0.2
Vidyut	8.4	.2	0.08	0.08	0.2	0.08	0.08	0.16	0.2	0.04	0.04	0.16	0.08	0.08	0.04	0.04	0.08	-	0.2

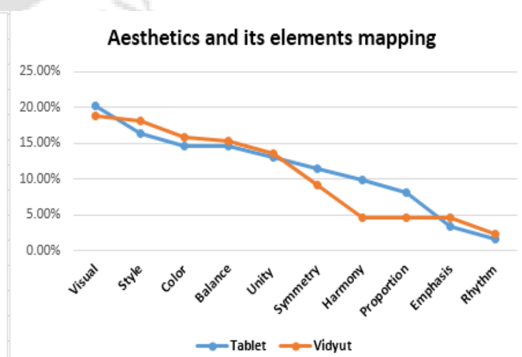
When all the design elements i.e. aesthetics, ergonomics and function are combined, the link index of the Vidyut laptop is higher with a value of 8.9. And in case of usability, operations and processes the Vidyut laptop has a value of 8.4, making it a more value-added product.

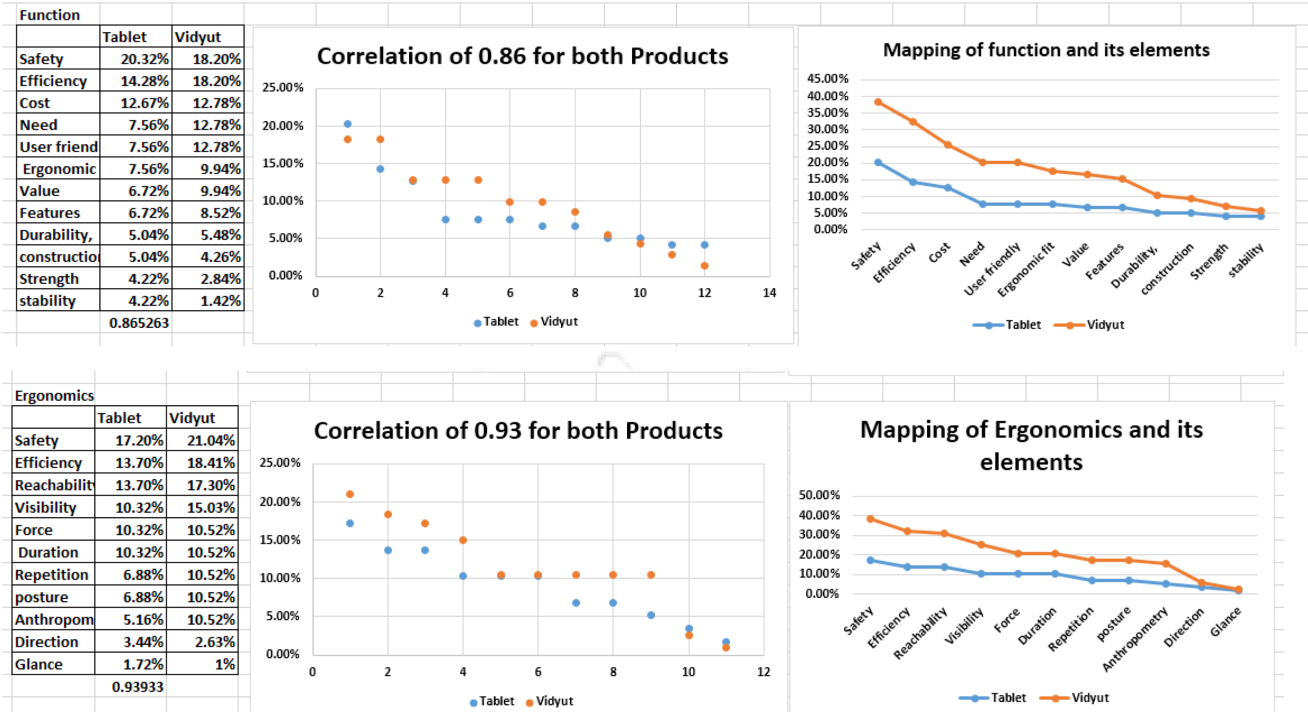
5.5.10. Based on prioritization of design elements for Akash Tablet and Vidyut laptop, correlation, mapping and trends

Correlation**,** mapping and trends for Tablet and Vidyut laptop

Aesthetics		
	Tablet	Vidyut
Visual	20.19%	18.89%
Style	16.30%	18.16%
Color	14.67%	15.89%
Balance	14.67%	15.35%
Unity	13.04%	13.62%
Symmetry	11.41%	9.08%
Harmony	9.78%	4.54%
Proportion	8.15%	4.54%
Emphasis	3.26%	4.54%
Rhythm	1.63%	2.27%
	0.927503	







Function

	Tablet	Vidyut
Safety	20.32%	18.20%
Efficiency	14.28%	18.20%
Cost	12.67%	12.78%
Need	7.56%	12.78%
User friend	7.56%	12.78%
Ergonomic	7.56%	9.94%
Value	6.72%	9.94%
Features	6.72%	8.52%
Durability,	5.04%	5.48%
constructio	5.04%	4.26%
Strength	4.22%	2.84%
stability	4.22%	1.42%
	0.865263	

Ergonomics

	Tablet	Vidyut
Safety	17.20%	21.04%
Efficiency	13.70%	18.41%
Reachabilit	13.70%	17.30%
Visibility	10.32%	15.03%
Force	10.32%	10.52%
Duration	10.32%	10.52%
Repetition	6.88%	10.52%
posture	6.88%	10.52%
Anthropom	5.16%	10.52%
Direction	3.44%	2.63%
Glance	1.72%	1%
	0.93933	

Figure 5.77: Aesthetics, function and ergonomics correlation and regression results and their trends

A correlation and regression analysis were computed for Tablet and Vidyut laptop (Pearson product-moment correlation coefficient) to assess the trends of design elements (Prioritized) and their weights for both the products. There was a positive correlation between all the prioritized design elements r=0.92, n=10, p=0.00011 for aesthetics and its elements, r=0.93, n=11, p=1.78E-5 for ergonomics and its elements and for function and its elements, r=0.86, n=12, p=0.00027. Overall, there was a strong, positive correlation between prioritized design elements for both the products. These rankings and weights can be utilized precisely in the designing phase. Similar trends were observed after mapping of all the elements.

5.5.11. Inferences on the computing devices

Here the question arises, how is the Vidyut laptop innovative? Since both the products are of the same family and have the same functioning, still the level of innovation is higher in Vidyut laptop. The answer here is to add more functionality and usability values to the Akash tablet. Even though the Akash tablet was indigenously developed at a cheaper cost and is doing well for the targeted customers. The modified version of Akash tablet is the Vidyut laptop, which is an innovative product that is slightly more expensive. Here the manufacturers of Vidyut laptop brought the design thinking and plan of action with innovation in mind. This product is surely helpful for the low computations and it offers similar features like a normal laptop. How did they achieve it?

A comparative analysis of Vidyut laptop and Akash tablets, yields the fact that, Vidyut laptop is more innovative compared to the latter. The addition on the functional elements makes the Vidyut laptop more innovative. The question to answer here is, what makes the product innovative? The answer is design thinking. This incorporates value in the form of add-ons and makes the product user centric from aesthetic, ergonomic and design perspective.

In analyzing both the products and plotting linkographs it was found that Vidyut laptop is more value added. They followed the methodology of collaboration, outsourcing and identified the extra features to be added into the existing tablet.

In this product already innovation has happened, and we have tried to answer questions such as, the extent of innovation? and how have they achieved the innovation in the Vidyut laptop? Hence, we generated the linkographs. It is like tracing back the design to find out how exactly did the innovation happened?

The consolidated results all the experiments are run through the proposed innovation frame work, and the findings are tabulated. The results are found to be consistent and it makes the frame work robust.

5.6 Linkogrpahs for the following products

In identifying the value addition through the linkograph, additional three products have been selected and Linkograph results are shown below.

 **Product A: Mechanical hand blender**	 **Product B: Electric blender**
 **Product A: Iron**	 **Product B: Iron**

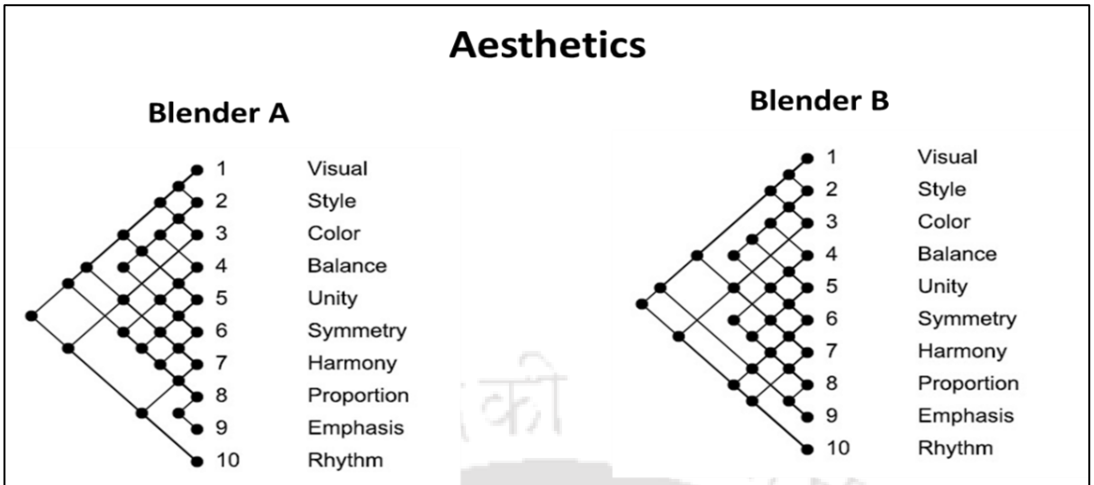
	
Product A: Steamer for garments	**Product B: Compact Steamer for garments**

5.6.1 Case study 5: Blender, Electric blender B and normal blender A

Here we have taken two blenders, electric blender is costly and a mechanical blender is cheap and efficient. Mechanical blender has a rack and pinion arrangement and works by triggering. It does not require any extra source like electric blender. It is light weight, cheap and handy. We have done linkograph analysis of these two products and results are shown below.

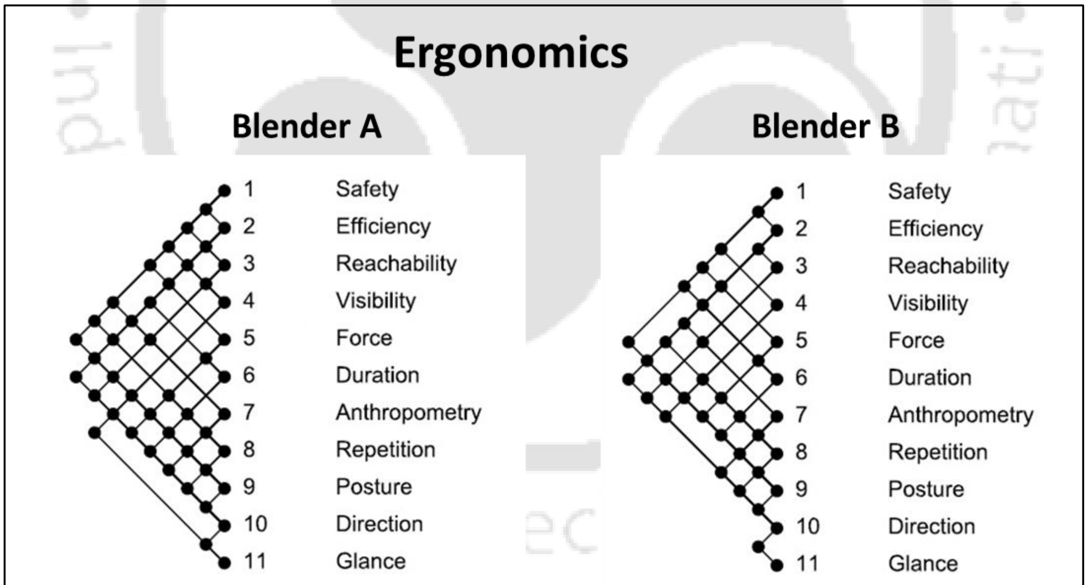
Product A, Mechanical blender **Product B Electric blender**

Figure 5.78: Blenders of both types



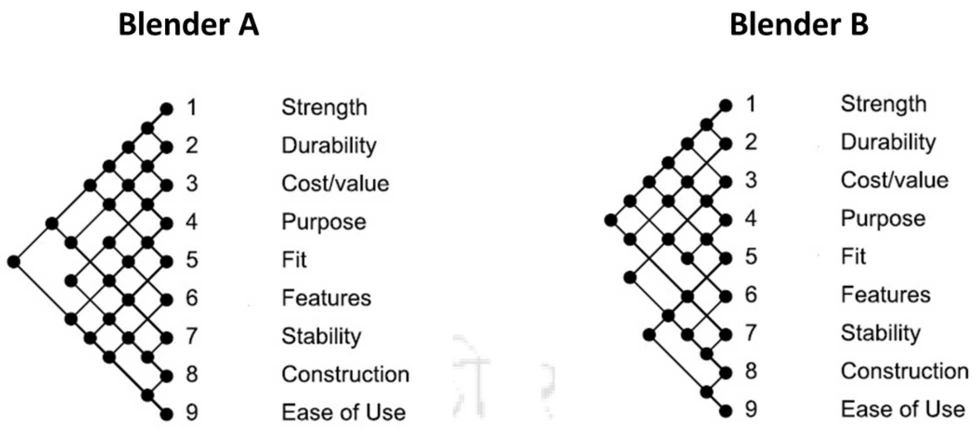
	No of Moves N	Link Index LI
Blender A(23,10)	10	2.55
Blender B(25,10)	10	2.

Figure 5.79: Linkographs for both Blenders aesthetics and its elements



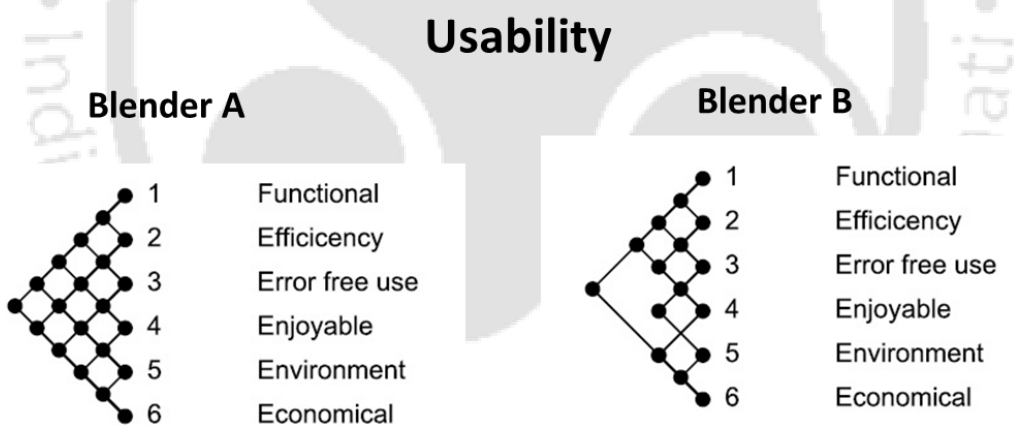
	No of Moves N	Link Index LI
Blender A(36,11)	11	3.27
Blender B(30,11)	11	2.72

Figure 5.80: Linkographs for both Blenders ergonomics and its elements



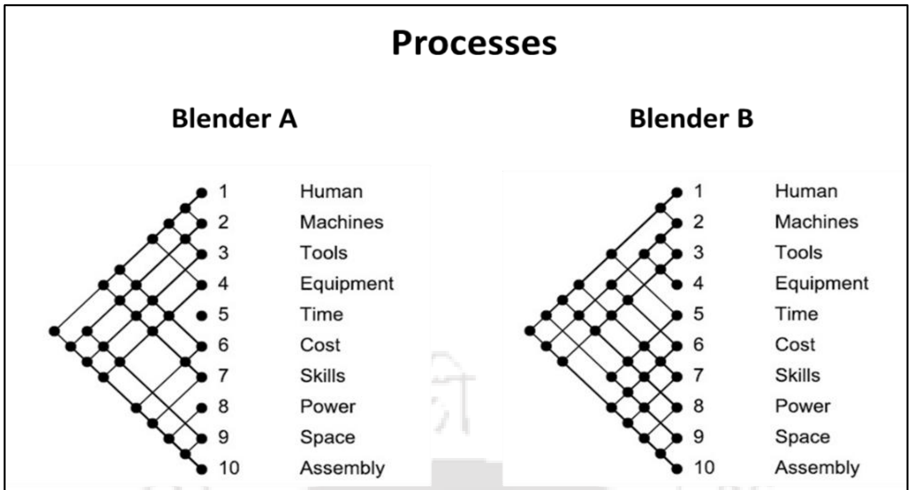
	No of Moves N	Link Index LI
Blender A(24,9)	9	2.6
Blender B(20,9)	9	2.2

Figure 5.81: Linkographs for both Blenders function and its elements



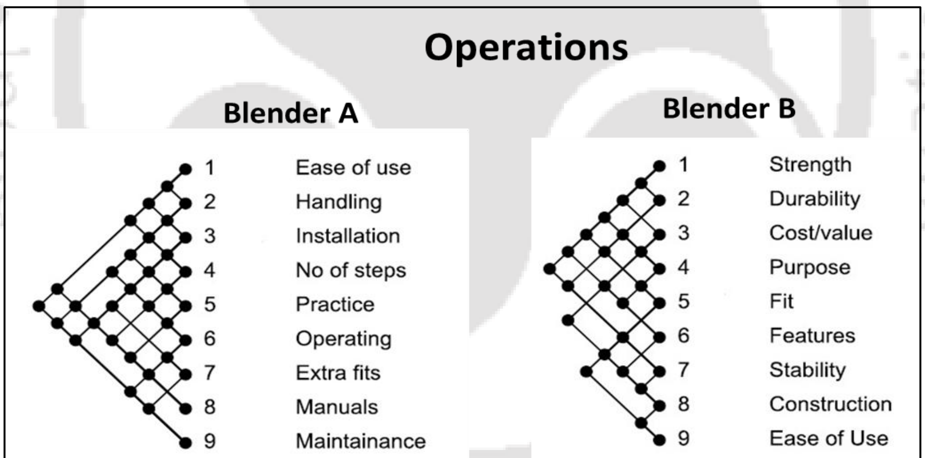
	No of Moves N	Link Index LI
Blender A(15,6)	6	2.5
Blender B(8,6)	6	1.33

Figure 5.82: Linkographs for both Blenders usability and its elements



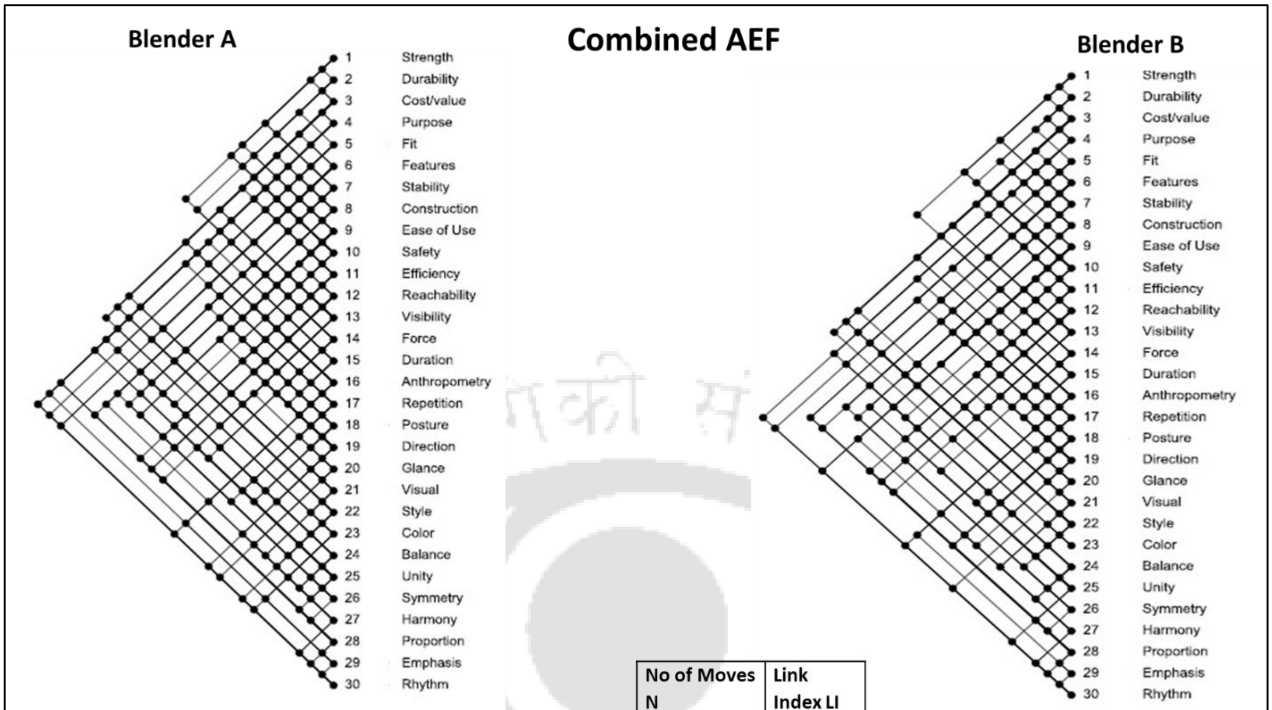
	No of Moves N	Link Index LI
Blender A(24,10)	**10**	**2.4**
Blender B(27,10)	**10**	**2.7**

Figure 5.83: Linkographs for both Blenders processes and its elements



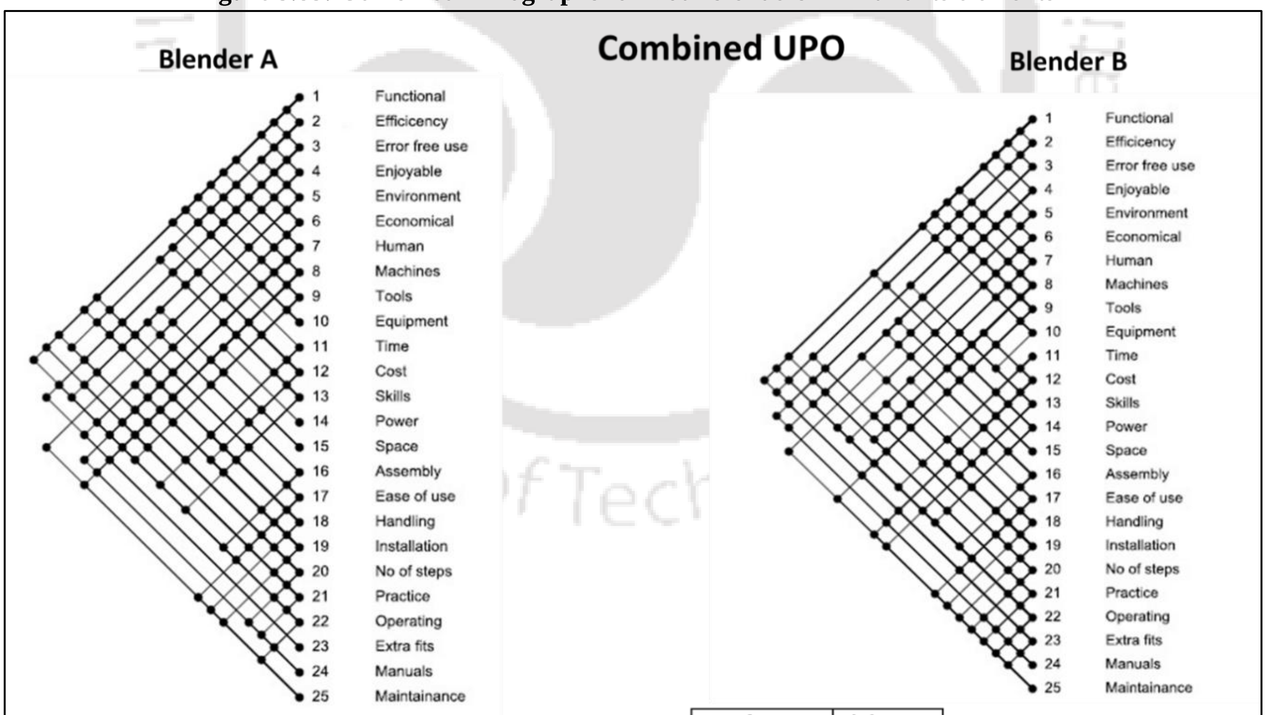
	No of Moves N	Link Index LI
Blender A(26,9)	**9**	**2.8**
Blender B(22,9)	**9**	**2.44**

Figure 5.84: Linkographs for Both blenders processes and its elements



	No of Moves N	Link Index LI
Blender A(178,30)	30	5.9
Blender B(152,30)	30	5.06

Figure 5.85: Combined linkographs for Both blenders AEF and its elements



	No of Moves N	Link Index LI
Blender A(133,25)	25	5.32
Blender B(132,25)	25	5.28

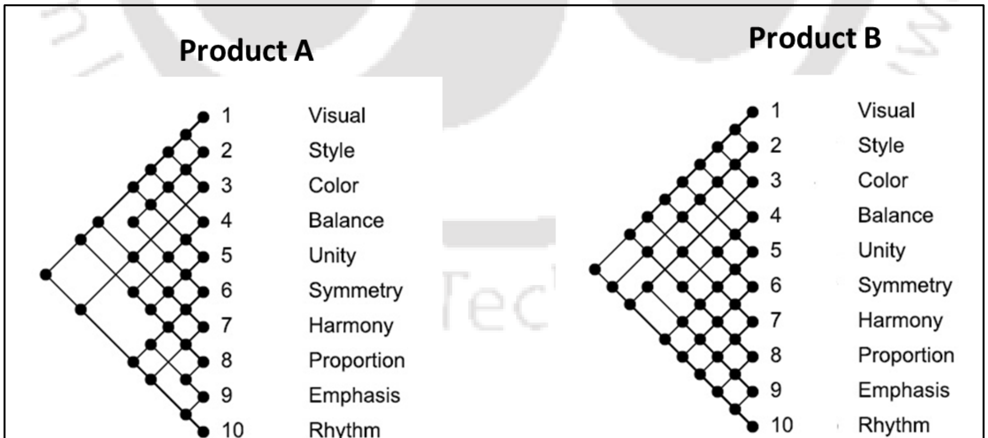
Figure 5.86: Combined linkographs for both Blenders UPO and its elements

Observing the link index of both products, there is a value addition in the mechanical type blender (Product A) than the electric blender. Hence the technique of developing linkogrpahs can give the value addition relatively.

5.6.2 Case 6: Garment Steamer, Big Steamer Product A, Compact Steamer Product B

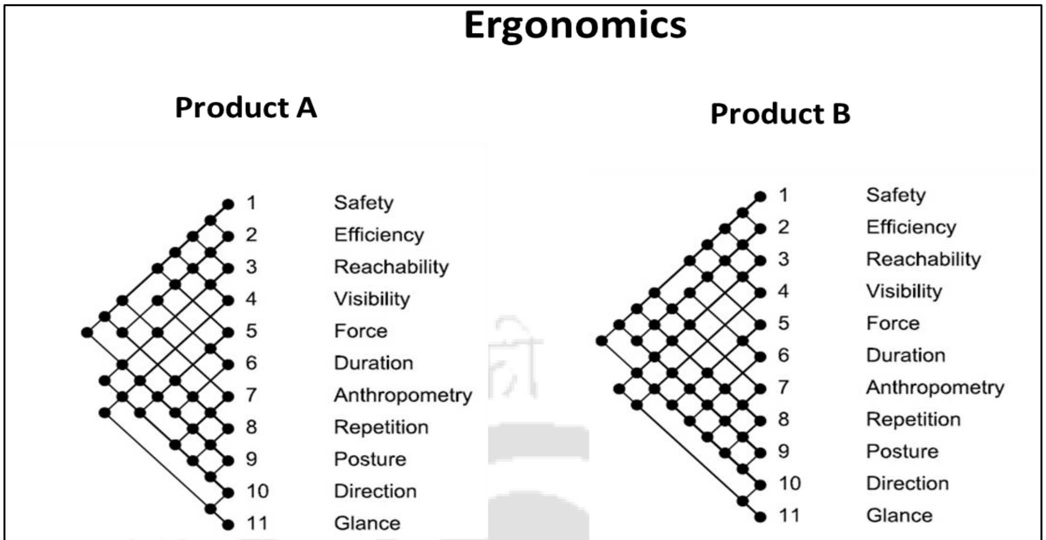
Figure 5.87: Shows both the Garment Steamers

These products are used as garment steamer one product (Product A) being big size, with wheels, and require an effort to finish the task. It has many attachments, each time one has to attach the fitment and work. Whereas the Product B is small compact and lightweight.



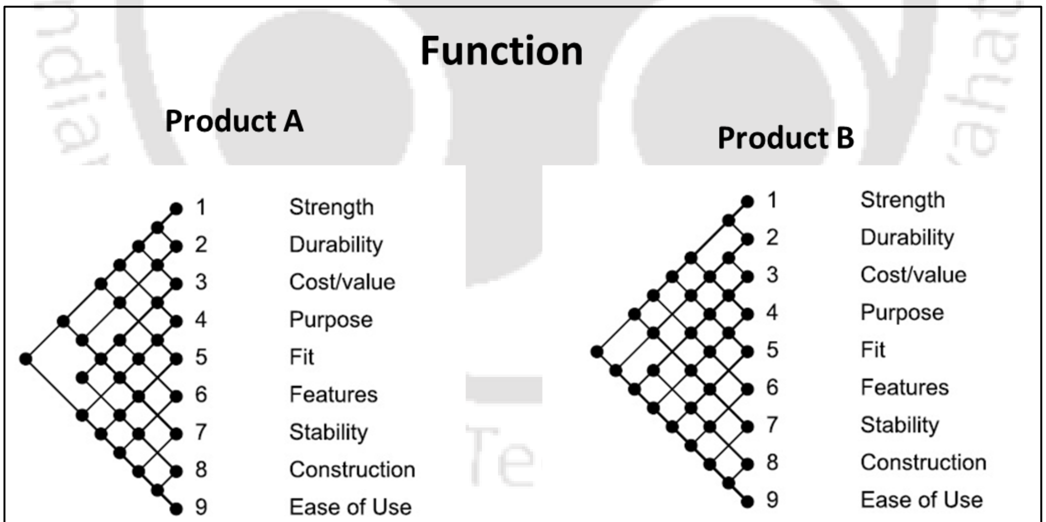
	No of Moves N	Link Index LI
Product A(27,10)	**10**	**2.7**
Product B (35,10)	**10**	**3.5**

Figure 5.88: Linkographs for both Garment Steamers Aesthetics and its elements



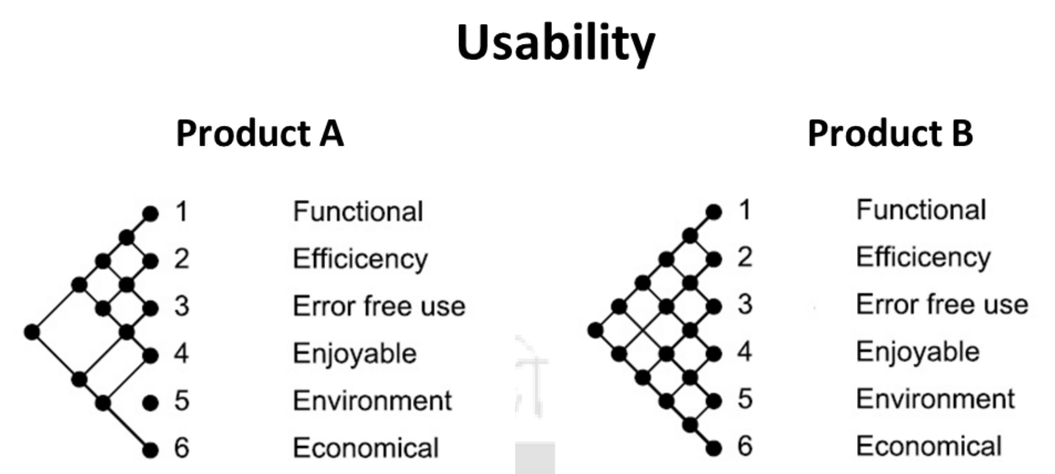
	No of Moves N	Link Index LI
Product A (32,11)	**11**	**2.09**
Product B(38,11)	**11**	**3.45**

Figure 5.89: Linkographs for Garment Steamers ergonomics and its elements



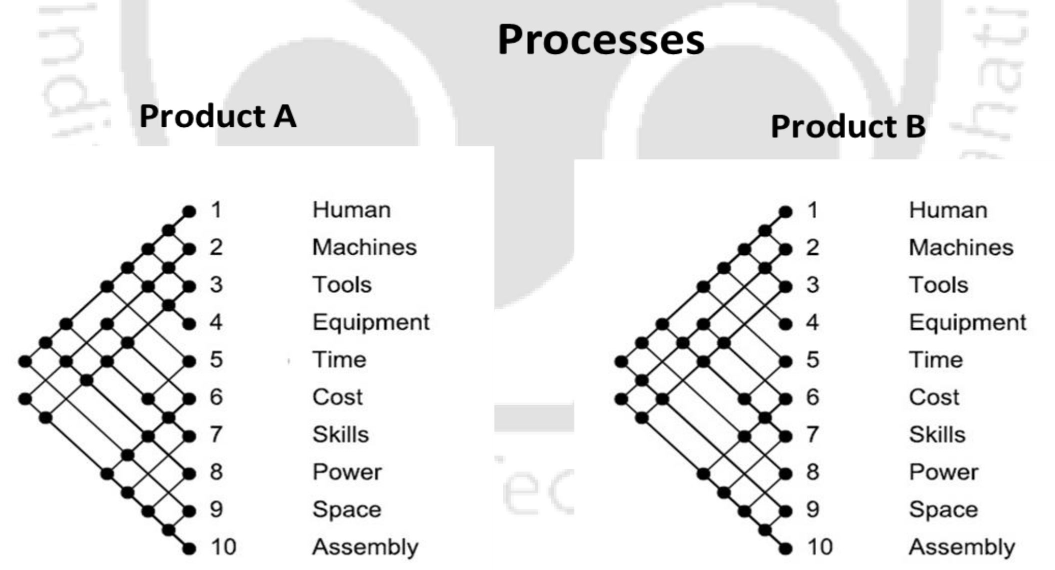
	No of Moves N	Link Index LI
Product A(25,9)	**9**	**2.77**
Product B(28,9)	**9**	**3.11**

Figure 5.90: Linkographs for Garment Steamers function and its elements



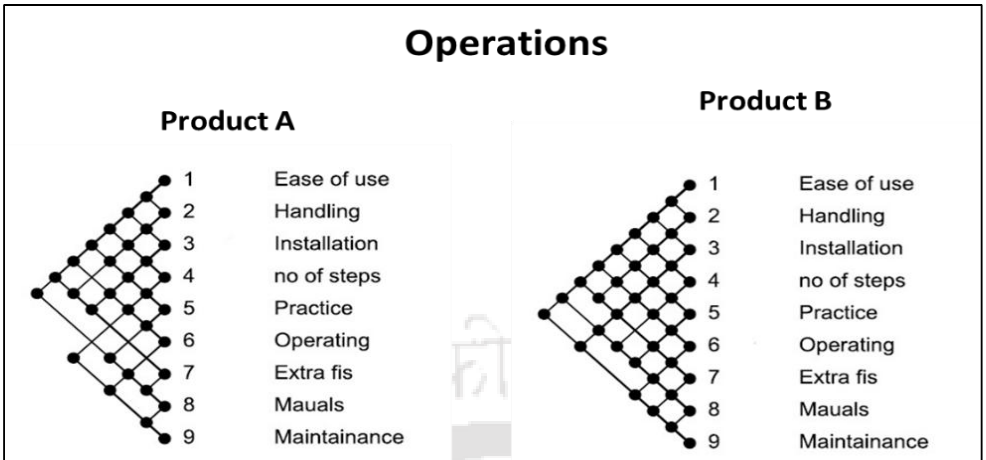
	No of Moves N	Link Index LI
Product A(9,6)	6	1.5
Product B(14,6)	6	2.33

Figure 5.91: Linkographs for Garment Steamers usability and its elements



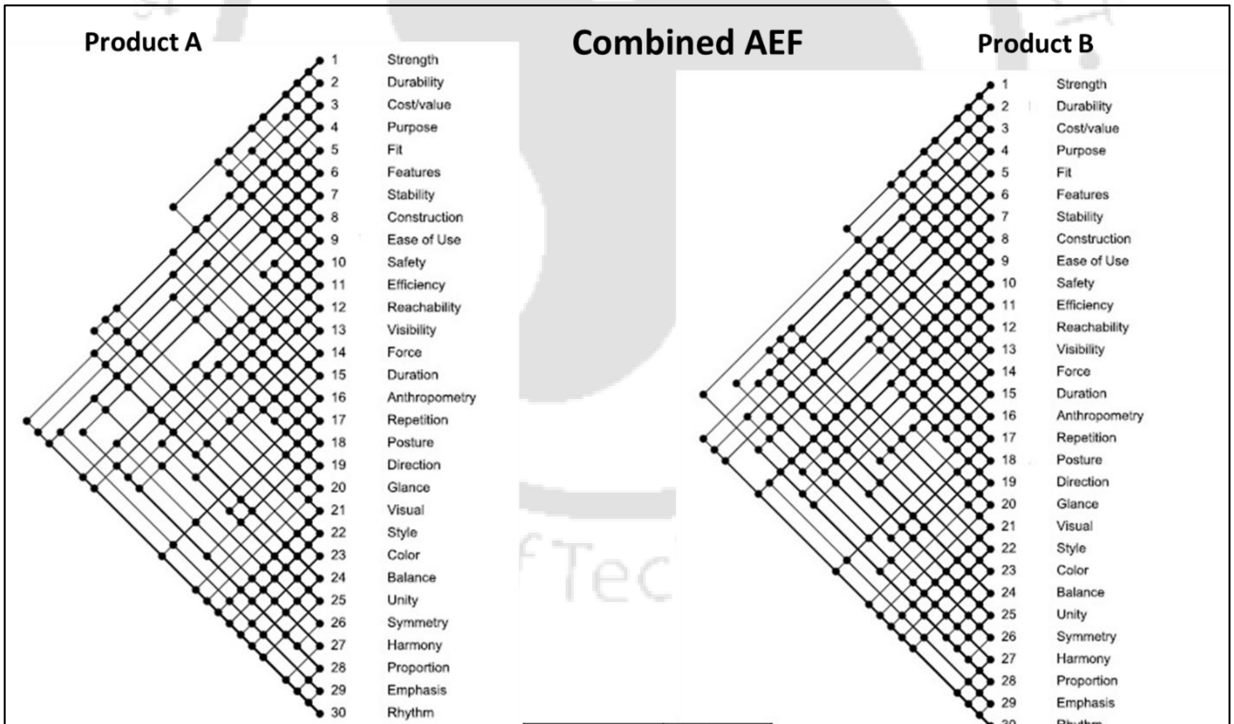
	No of Moves N	Link Index LI
Product A(25,10)	10	2.5
Product B(23,10)	10	2.3

Figure 5.92: Linkographs for Garment Steamers processes and its elements



	No of Moves N	Link Index LI
Product A(24,9)	9	2.66
Product B(31,9)	9	3.44

Figure 5.93: Linkographs for Garment Steamers operations and its elements



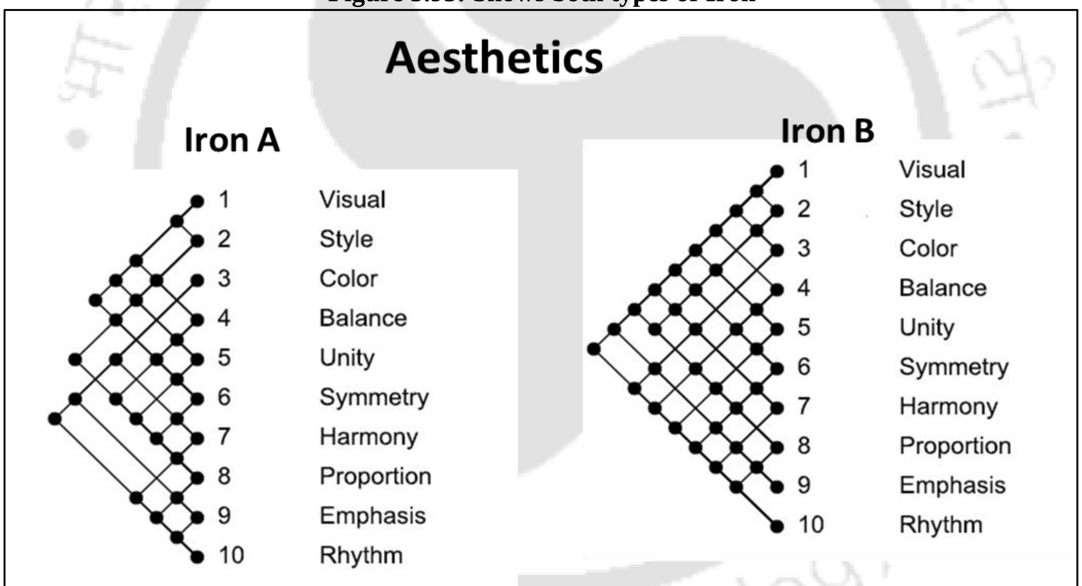
	No of Moves N	Link Index LI
Product A(171,30)	30	5.7
Product B(204,30)	30	6.8

Figure 5.94: Combined linkographs for both Garment Steamers AEF and its elements

Observing the link index of both products there is a value addition in the Product B than Product A. Hence the technique of developing linkographs can give the value addition relatively.

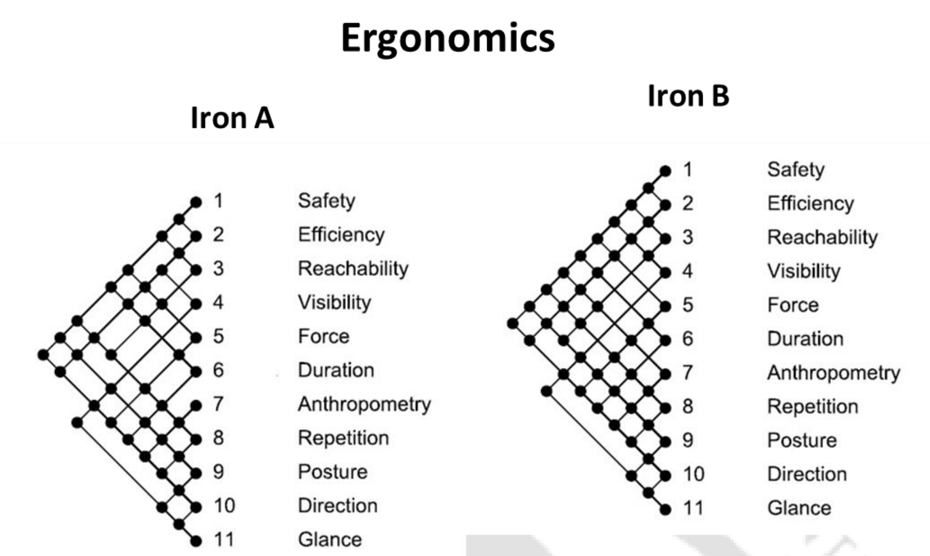
5.6.3. Case 7: Iron, Normal Iron Product A, Iron with steamer, lightweight Product B

Figure 5.95: Shows both types of Iron



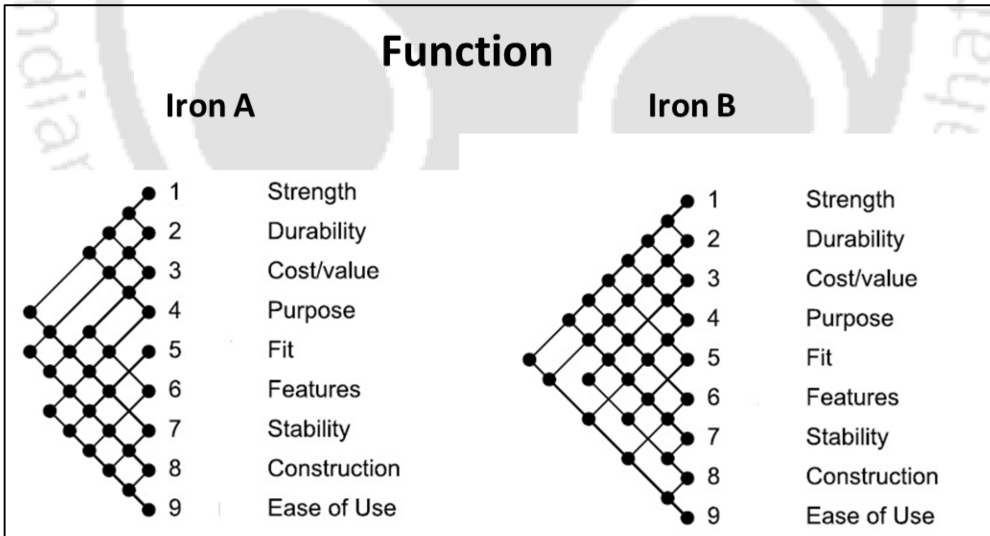
	No of Moves N	Link Index LI
Iron A(23,10)	10	2.55
Iron B(32,10)	10	3.2

Figure 5.96: Linkographs for both Irons Aesthetics and its elements



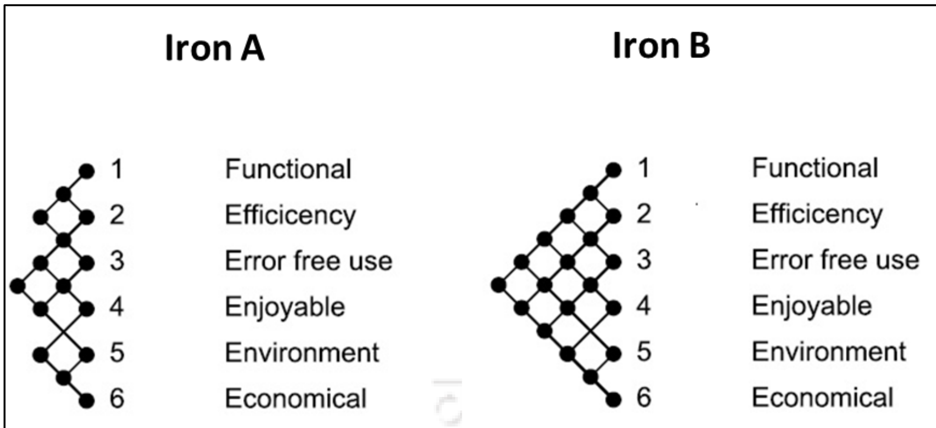
	No of Moves N	Link Index LI
Iron A(35,11)	11	3.18
Iron B(40,11)	11	33.63

Figure 5.97: Linkographs for both Irons ergonomics and its elements



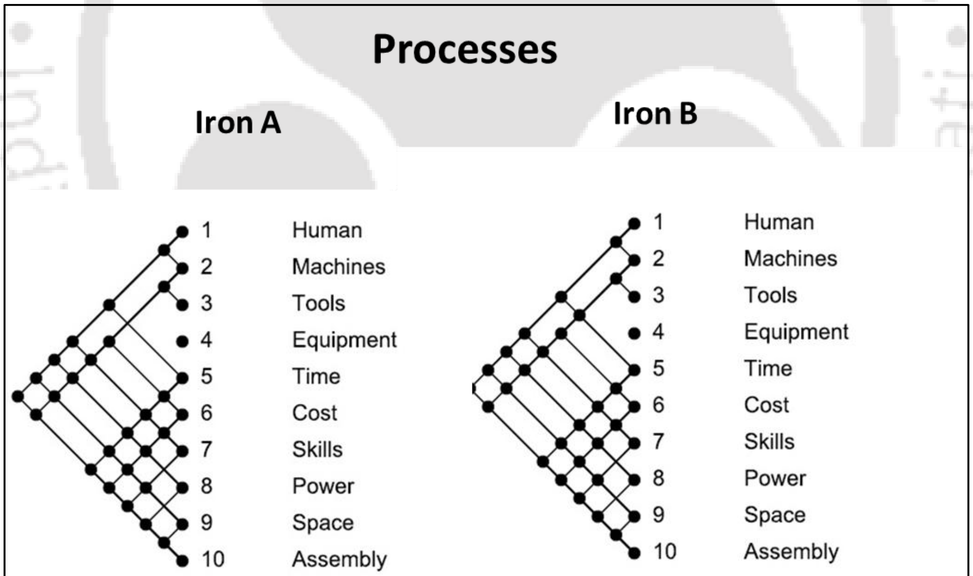
	No of Moves N	Link Index LI
Iron A(24,9)	9	2.66
Iron B(27,9)	9	3

Figure 5.98: Linkographs for both Irons function and its elements



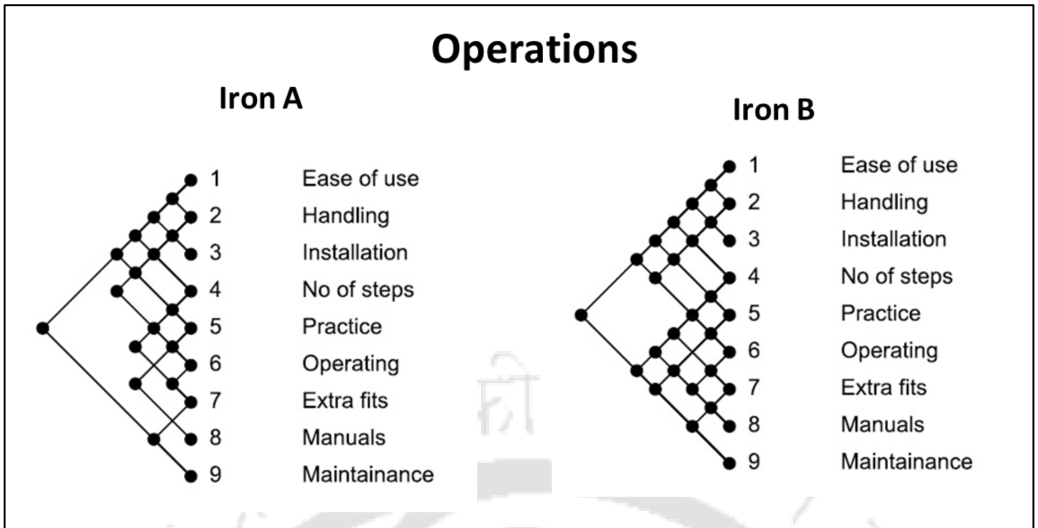
	No of Moves N	Link Index LI
Iron A(10,6)	6	1.66
Iron B(15,6)	6	2.5

Figure 5.99: Linkographs for both Irons usability and its elements



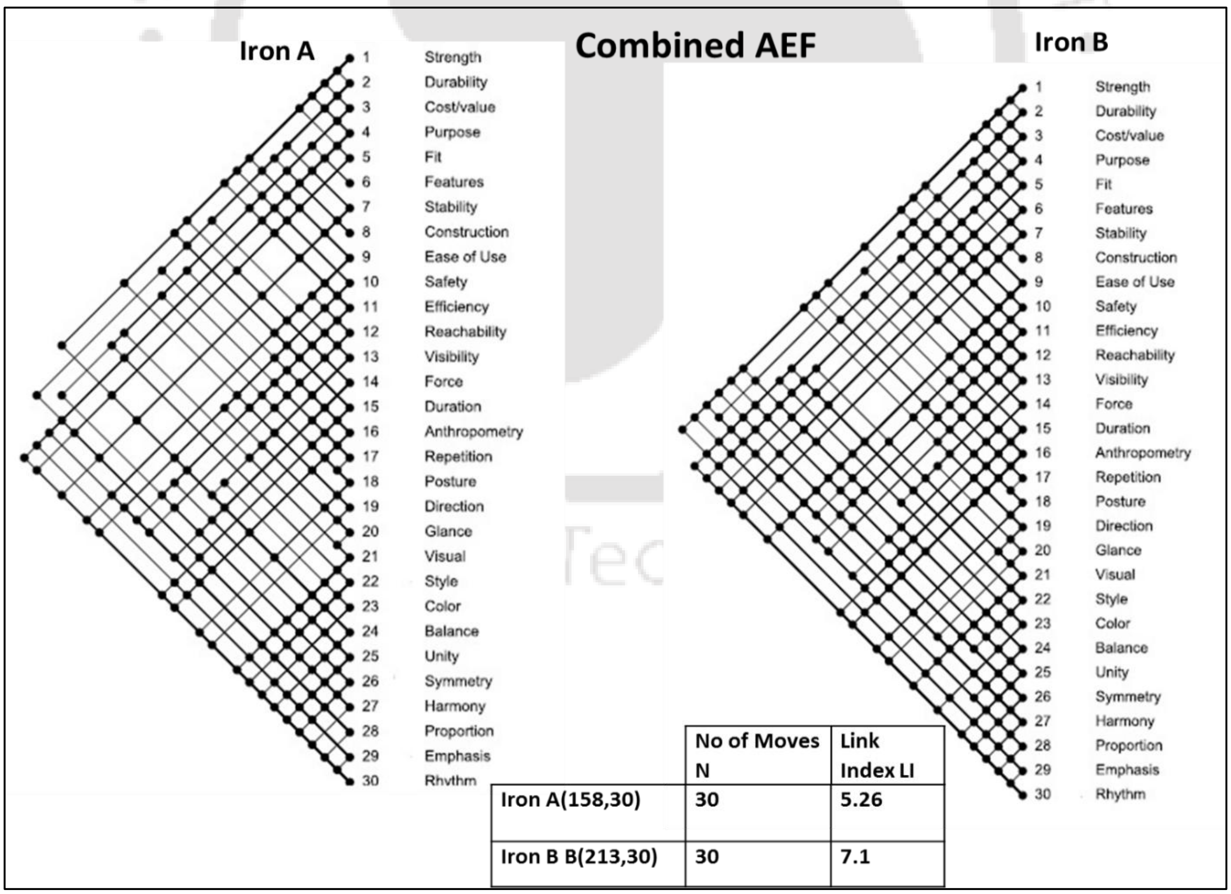
	No of Moves N	Link Index LI
Iron A(25,10)	10	2.5
Iron B(26,10)	10	2.6

Figure 5.100: Linkographs for both Irons processes and its elements



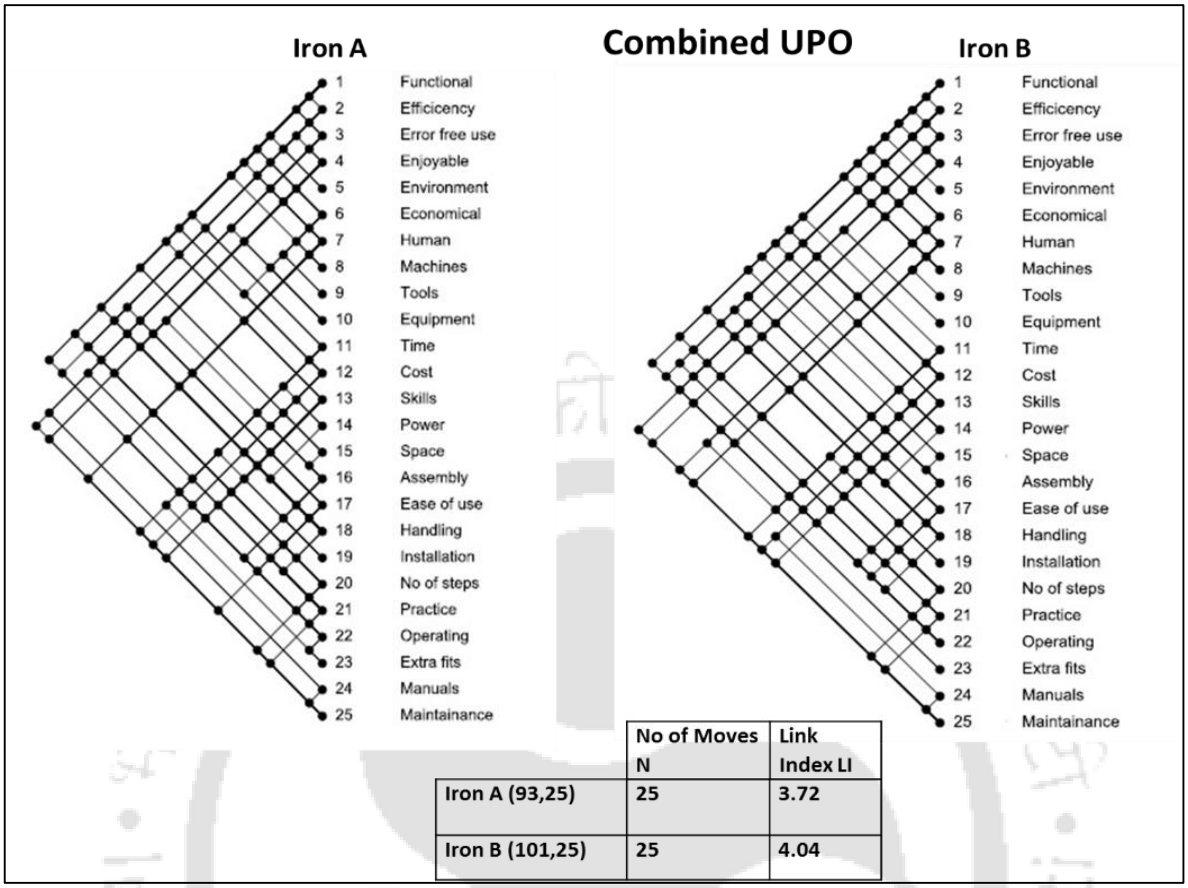
	No of Moves N	Link Index LI
Iron A (16,9)	**9**	**1.77**
Iron B (21,9)	**9**	**2.33**

Figure 5.101: Linkographs for both Irons operations and its elements



	No of Moves N	Link Index LI
Iron A(158,30)	**30**	**5.26**
Iron B B(213,30)	**30**	**7.1**

Figure 5.102: Combined linkographs for both Iron AEF and its elements



	No of Moves N	Link Index LI
Iron A (93,25)	25	3.72
Iron B (101,25)	25	4.04

Figure 5.103: Combined linkographs for both Iron UPO and its elements

Observing the link index of both products there is value addition in the Product B than Product A. Hence the technique of developing linkographs can give the value addition relatively.

5.6.4. Conclusions from the analysis

The results indicate that prioritization of design elements can provide insights to the gaps which have potential for value addition through innovation. The results of prioritized chart permit the designer and MSMEs to quickly access, check and take action in the designing process as well as improving the existing products by saving, time, number of iteration and wastage of prototypes before launching a new product. In this study, we focused on the prioritizing of the design elements starting from design space with two case studies as pilot studies and extended it with another four cases as experimental work. For measurement of relative innovation index of the products, we developed linkographs, link index and critical moves. It also gives the spots of building the relations amongst the design elements and improving the product.

The frame work is built up based on all the case studies which have undergone the procedure, as observed from pilot studies and main experiments. And to conclude we found that the frame work is very rigorous and strong. The next step would be validation through the field survey for the proposed frame work, this is discussed in the next chapter. Consolidated findings of all the experiment results are tabulated as shown in Table 5.45.

Table 5.45: Consolidated findings of all the experimental results

Products	Technical design	HCD, Usability Test	Concept generation	Redesigned/ Improved	Prioritization	Correlation	Innovation index	Validated	Proved
Ear wax remover	√	√	√	√	√			√	√
Solar powered Auto cooler for car	√	√	√	√	√			√	√
Opener A	√	√	√	√	√	√	√	√	√
Opener B	√	√	√	√	√	√	√	√	√
Opener C	√	√	√	√	√	√	√	√	√
Umbrella A	√	√	√	√	√	√	√	√	√
Umbrella B	√	√	√	√	√	√	√	√	√
Umbrella D	√	√	√	√	√	√	√	√	√
Rain coat	√	√	√	√	√	√	√	√	√
Chinese Envelop maker	√	√	√	√	√	√	√	√	√
Lab Made Envelop maker	√	√	√	√	√	√	√	√	√
Akash Tablet	√	√	√	√	√	√	√	√	√
Vidyut Laptop	√	√	√	√	√	√	√	√	√
Blenders (2)							√	√	√
Iron(2)							√	√	√
Garment streamer							√	√	√

Summary of chapter 5: In this chapter detailed product analysis has been covered through various case studies. This chapter outlines the method of conducting product analysis and basic idea of incorporation of innovation in the products. Each step has been interpolated on to the proposed frame work for innovation. The results of Linkographs have been discussed with reference to the innovation index. The frame work for innovation and validation using design case, and the detailed results and discussion have been carried out in the next chapter.

Chapter 6

6. Validation of the proposed innovation frame work - Measuring innovation by an Index

Abstract: This chapter reports the field study data analysis as the part of validation. The product analysis, generation of linkographs has been discussed in previous chapter. The proposed frame work has been validated by qualitative analysis, it focusses on the Qualitative analysis of the responses given by 10 MSMEs along with the extracted results. The contributions of the research in both practical and theoretical ways enlisting the future scope are discussed in the next chapter.

6.1 Introduction

In the earlier chapters the methodology of experimental design, research instrument, data collection techniques and proposed frame work of innovation building was discussed. A frame work for innovation was proposed and seven product cases were analyzed to measure the innovation index relatively. The current chapter deals with compilation of the data collected, inferences and interpretations drawn from the analysis and validation of the proposed innovation metrics, i.e. quantifying the degree of innovation of a given set of products, prioritization of design elements and establishing a new framework that aids innovation in products etc.

Based on the weights and the rankings, prioritization of the design elements, for all the products under study were done. It is posited that, this helps the designers and MSMEs to prioritize the variables of prime importance while designing the product. The closeness of innovation has incorporated between the products has been observed form the trends generated from correlations. The innovation has happened in micro-steps which needs to be quantified through the Linkographs. The Link indexes give the relative innovation indexical value.

6.2 Towards validating the developed frame work

The final innovation frame work is represented in Fig. 6.1.

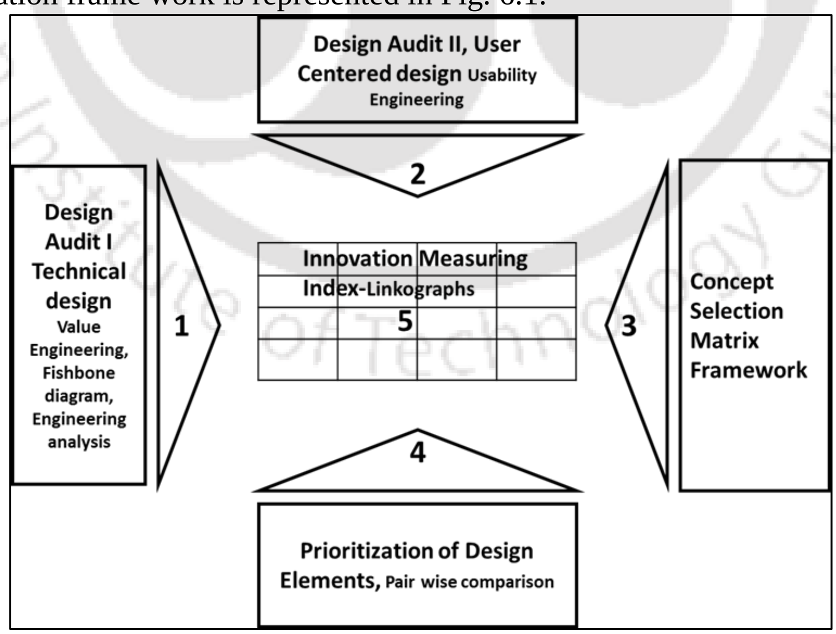


Figure 6.1: Final frame work of proposed innovation metrics

6.2.1 Measuring innovation index:

From the section 4.5, innovation and creativity Table 4.2, innovation potential can be measured (equation 2). Section 2.13 in chapter 2 discussed about the innovation frame work and drawbacks leading to the conclusion that, as of now, there is no perfect single tool which can measure the innovation index of the product that are manufactured by Indian MSMEs. We aimed at developing a framework for innovation. We explored through experimentation, framework for measuring and compare innovation for given set of products. The proposed frame work for innovation is developed on the basis of 'Design space theory' and ISO standards. The building of the frame work started with the pilot study of two products. The initial phase being - understanding of the products, derived after the 'Design Audit'. Design audit is constituted with technical design including Value engineering analysis, Fish bone diagram and Engineering analysis, giving all the technical information about the product. In another part of audit, we have adopted the UCD in which usability audit has been incorporated, as maximum possibility of adding innovation.

Other part of the proposed frame work is prioritizing the design elements, based on the developed novel fractal triangle of innovation as discussed in chapter 4, Fig 4.7. And accordingly all the design elements were recorded. These need to be prioritized as it involves lot of time in identifying ratios between elements. It also focusses on the elements that need to be emphasized during the product design phase. The pairwise comparison method and correlations of the elements contribute in prioritizing design elements, helping in value addition in the product.

The other dimension of the frame work is concept selection matrix, it was carried out with first two phases of design audit, leading to concept generation. One needs to have a matrix for selecting the best concept out of the generated concepts. We have developed the framework matrix for selecting the concepts which is easy and one can quickly calculate the sheer innovation potential and assign the weights and rankings. This sheer innovation potential gives the value based on certain criteria and not any comparable index.

The central objective of the research is to develop an innovation index measuring technique. Graph theory based technique called 'Linkographs' were generated. These linkographs unfold the design moves while a designer designs a product i.e. it helps in quantifying the cognitive thought process. Hence, this technique was used in identifying the spots of innovation that are incorporated in the product. Under each parameter such as aesthetics, ergonomics, function and usability etc. the sub-parameters are plotted using linkographs. This yields the link index, individually and is combined as shown in chapter 5, under each cases. From this, the exact spots of innovation can be observed and improved further when two products of the same family are compared. It helps in redesigning of the product after conducting the design audit. The link indices are nothing but the Innovation Indices (I_I).

Recalling from chapter 5, section 5.2.13, we reproduce here a case of product Bottle Opener. In the case of bottle opener (A), when further improvement is incorporated the Link index/Innovation Index changes as shown in Table. 6.1. Before conducting redesign and design audit innovation index I_I was 2.2 and after the audit and redesigning the I_I has the value of 2.55 i.e. relatively 0.33 more value addition has been incorporated in terms of function and it's elements.

Table 6.1: After building the relations improved link index

Before degenerated matrix							
	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6
Product A	9	**2.2**		55.5	33.3		11.1
Product B	9	1.88		33.3		22.2	

After saturated matrix							
	No of Moves N	Link Index LI	%CM2	%CM3	%CM4	%CM5	%CM6
Product A	9	**2.55**		55.5	33.3		11.1
Product B	9	1.88		33.3		22.2	

Hence, by observing all the indices we can infer that the proposed frame work for innovation indexing is capable of measuring relatively I_I. From the frame work, for identified openers, we are in a position to measure the I_I. Also the frame work facilitates in developing new type of product or redesigning of the products. In order to validate further, a questionnaire was given to ten MSMEs and details are furnished in section 6.3.

6.3 Qualitative validation of the proposed frame workwith MSMEs

6.3.1 Field Study Survey plan

The survey plan is shown in Fig. 6.2. We have compiled our results through the experiments conducted on seven products and in a position to determine a relative innovation index.

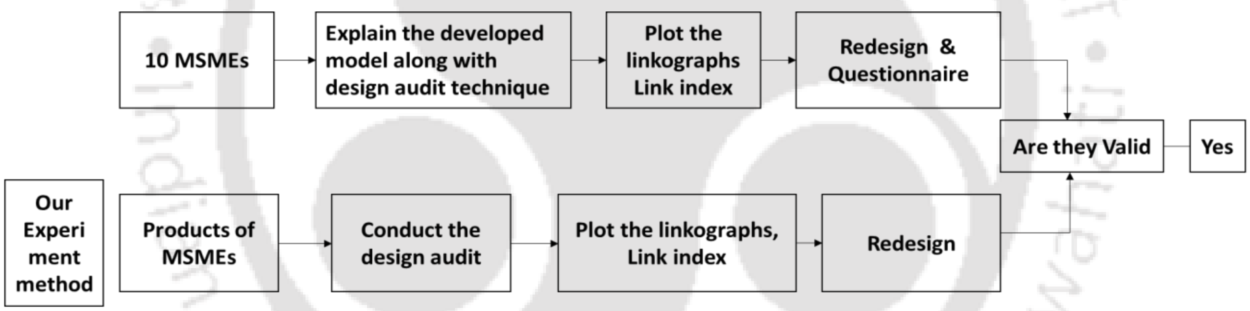
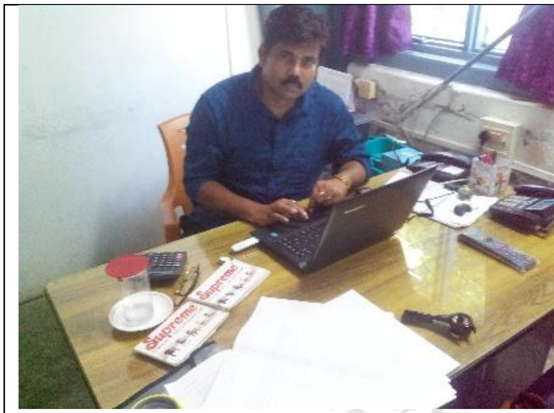
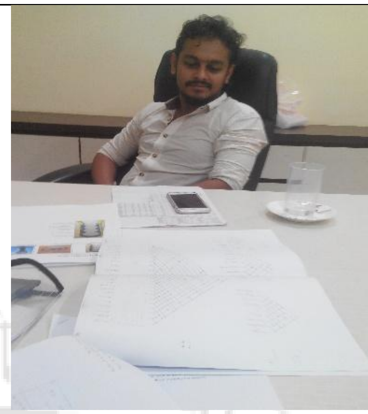
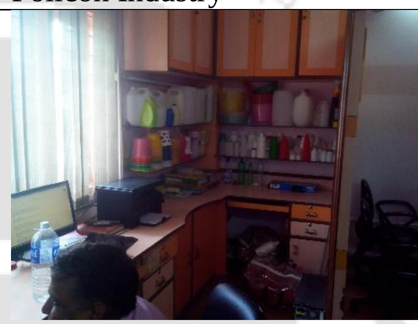


Figure 6.2: Schema for field survey and validation of the frame work

The survey was conducted through a face to face Questionnaire in order to validate our method with the ten responding MSMEs. Out of 25 MSMEs chosen we approached 10 MSMEs. In each MSME around 3 hours was the duration of discussion and total time spent on discussion was 30 hours. The discussion included explaining, discussing our method and demonstration of plotting the linkographs. We showed them the methodology of our experiment and interpretation of the results for their benefit. The feedback was taken through a questionnaire. Some of the survey, discussion photographs are shown in Table 6.2. The discussion involved designing of products, nature of products, machines, tools, methods, workers, employees, teams, margins, culture, salaries, material and profits etc.

Table 6.2: MSME respondents during the explanation of our model

 Supreme Industry	 Policon Industry
 Thakaria Poly mech Industries	 Adarsh industry

6.3.2 Qualitative analysis of the responses given by 10 MSMEs

When we observe the results of the questionnaire qualitatively, it is noted that results are found to be satisfactory. We can observe that maximum respondents are positive about the method proposed as such simple type of methods are not available for MSMEs. As an initiation with this method, we demonstrated our method, made them to understand our procedures, took their product and demonstrated precisely what has been done and then responses were collected. As a result, we found that this method can be used in MSMEs in comparing two or more products. Secondly, we can identify the relative innovation index of the given products through linkographs. This was liked and appreciated by all respondents as it provides the exact spaces/spots for improvement in the product. The responses were analyzed qualitatively for all 10 MSME respondents. And for each question (Questionnaire Appendix A) extracted details were documented and discussed as shown below.

Q1. Would you identify the innovation capabilities of our method?
All the 10 responded that our tool is capable of identifying the spots of innovation in the products.

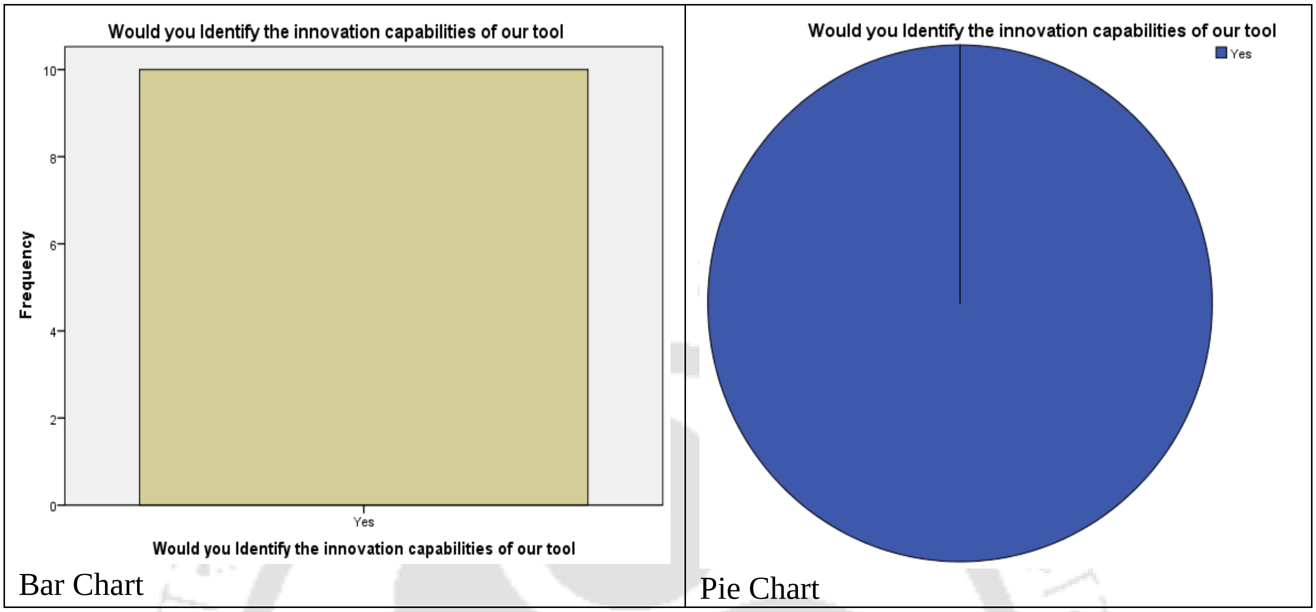


Figure 6.3: Identifying the innovation capabilities of our method

Q.2. What is the percentage of innovation that can be raised and where can it be incorporated?
Majority of responses (6) considered up to 20% innovation can be carried out in the product if they use our method. 3 responded as 10% increase in their product development phase if they carry this exercise. Only 1 response said 10% increase is possible.

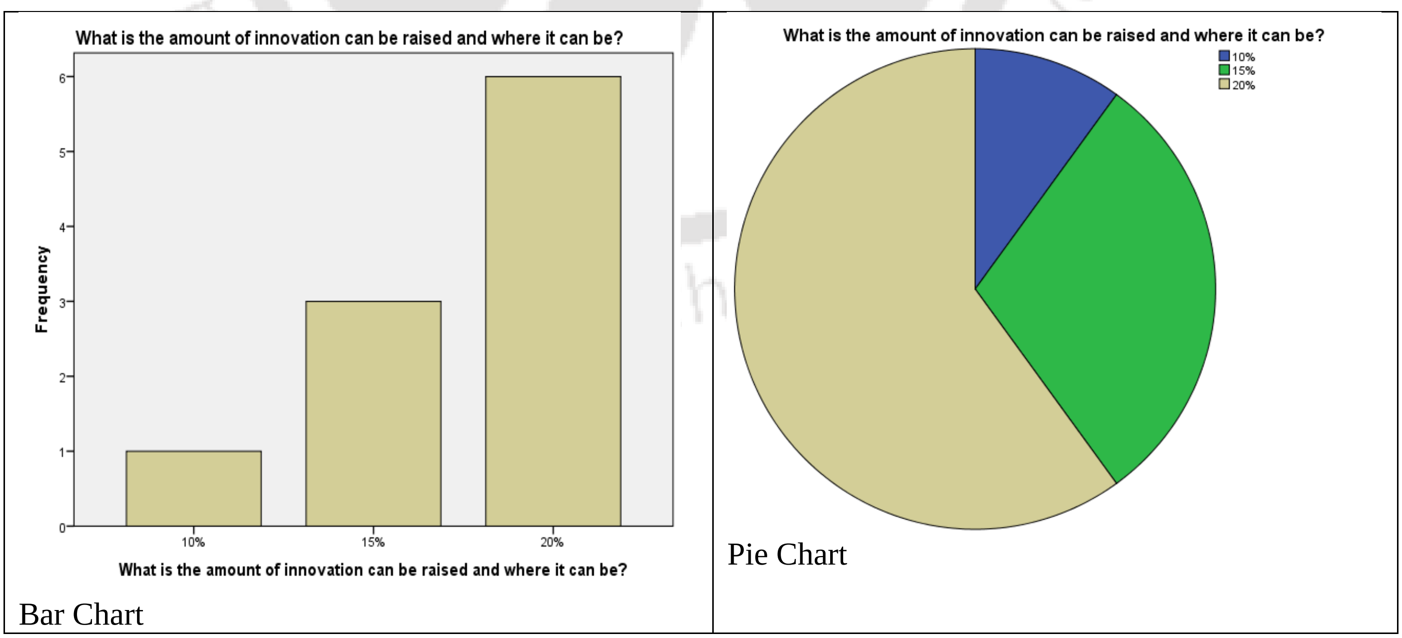


Figure 6.4: Amount of innovation can be raised in a product

Q.3. How much more value can be added in terms of innovation?

4 responded that up to 10% and another 4 said 20% value addition can be carried out in the product if they use our method. 1 responded saying 15% increase can be achieved in their product development phase if they carry out this exercise. 1 responded that 50% increase is possible.

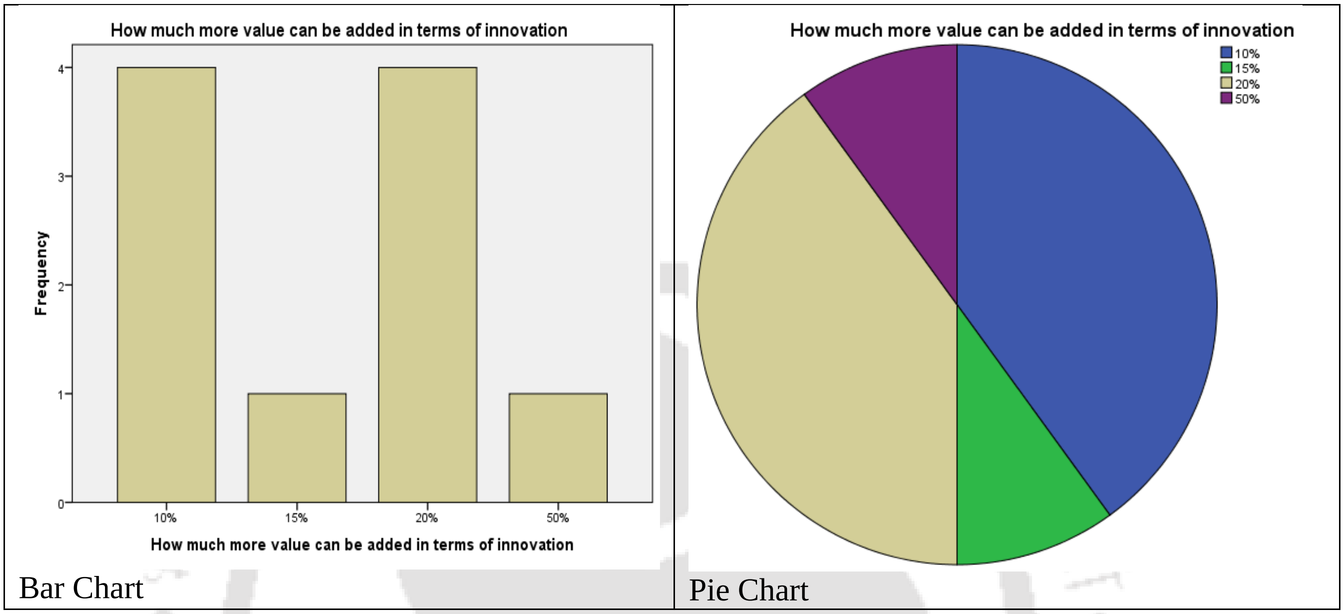


Figure 6.5: Amount of value can be added in a product

Q.4. Do you think we can use this method for coming up with a completely new product?

The majority of responses (8) responded positively and said that they can come up with a completely new product if they carry out this method and 2 responded that it was difficult for them to implement.

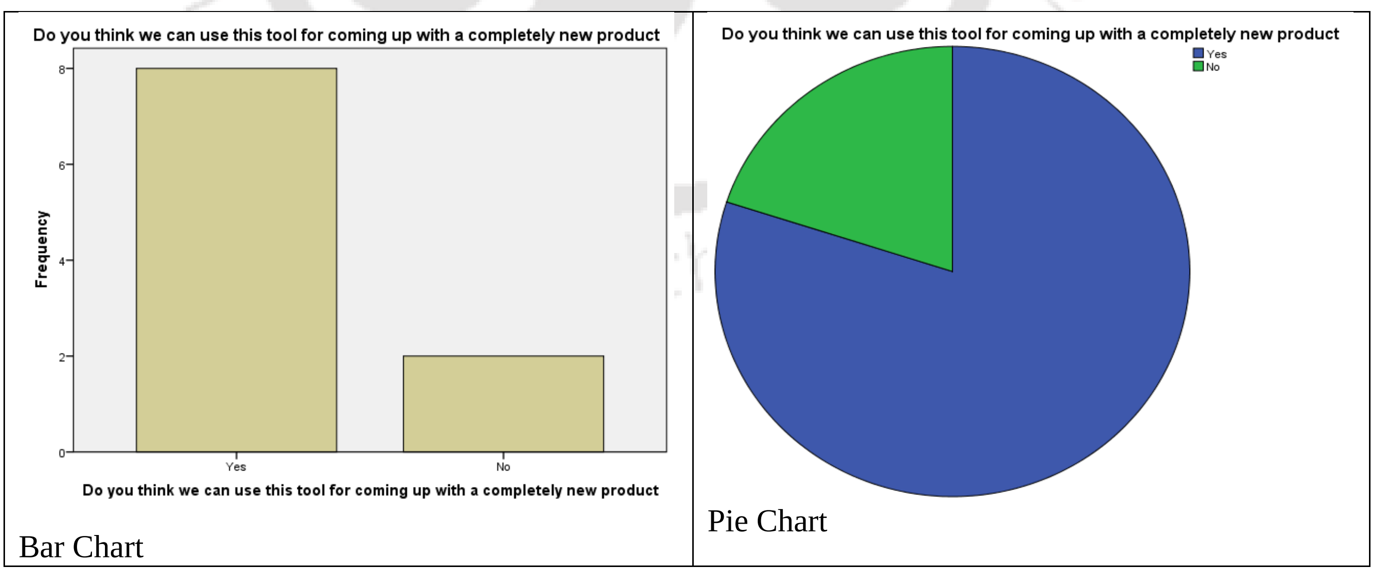


Figure 6.6: The % coming with new product

Q.5. How well, will our method perform to meet your needs?

All 10 responded saying that the tool meets their needs.

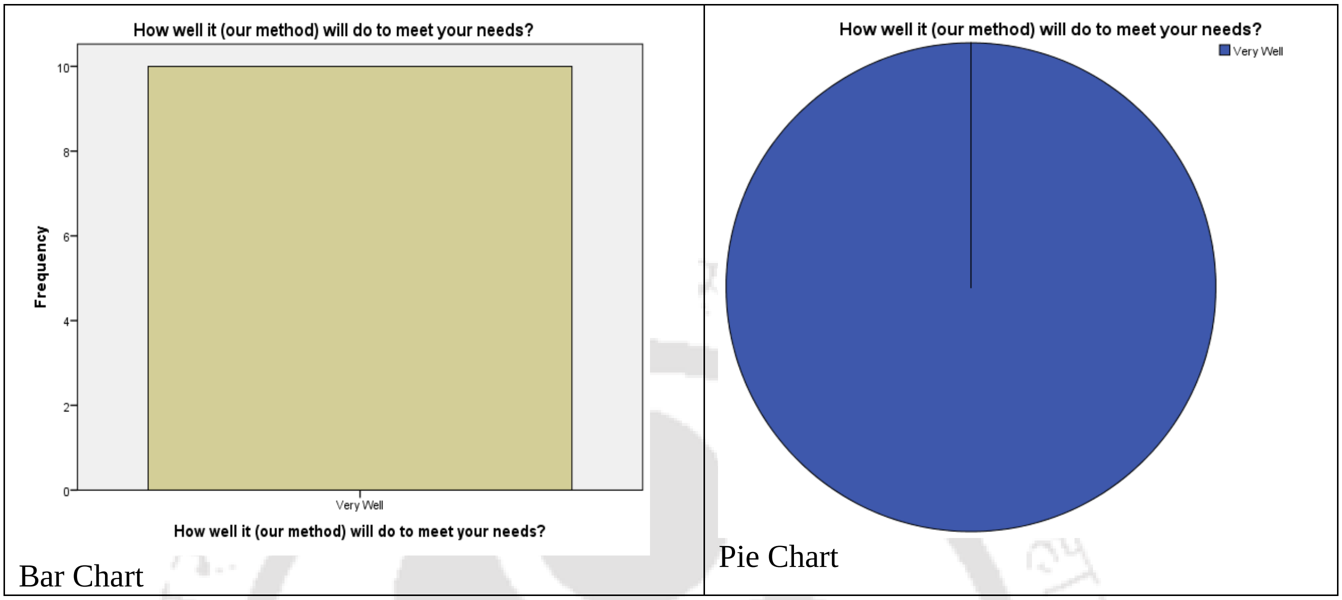


Figure 6.7: Meeting needs of MSMEs

Q.6. How likely are you going to practice our method of measuring innovation relatively?

The majority of responses (9) said they are very likely to practice it and the remaining 1 said that they are extremely likely to practice.

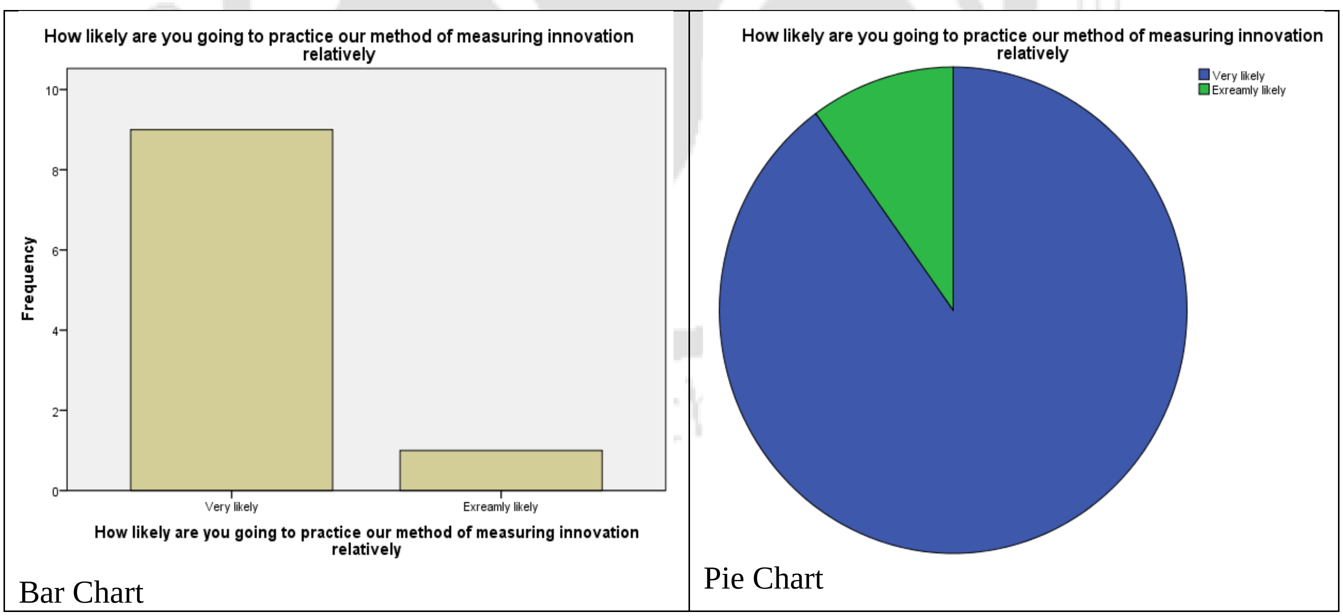


Figure 6.8: How likely are you going to practice our method?

Q 7. By using our frame work are you, now in a position to identify the difference between your product and the competitor's product?

The majority of responses (6) strongly agreed in identifying the difference between their product and the competitor's product. The remaining 4 agreed to identify the difference between the products.

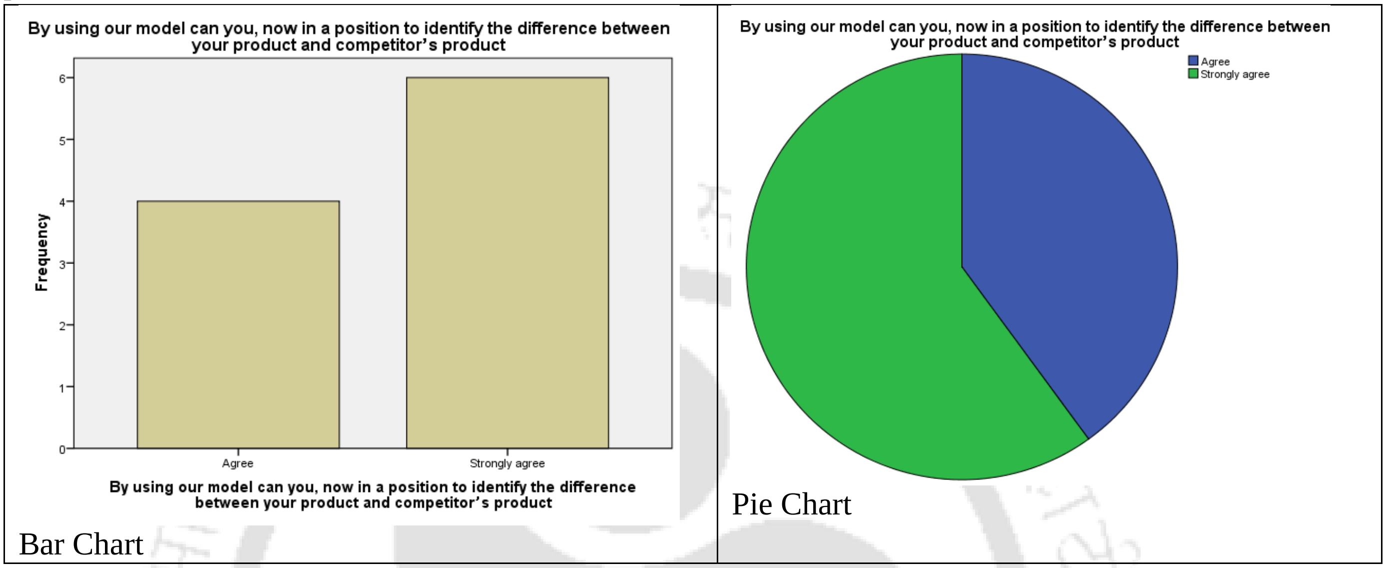


Figure 6.9: To identify the difference between your product and the competitor's product

Q.8. When you have used our model and identified few features and aspects that can bring innovation, please estimate how much sales or profit would your product fetch after the modifications?

The majority of responses (7) considered increasing the sale price up to 10%. 1 responded that they consider increasing the sale price by 20% in the product if they achieve innovation by carrying this exercise. Another, 2 said 15% increase is possible in their sales and profits.

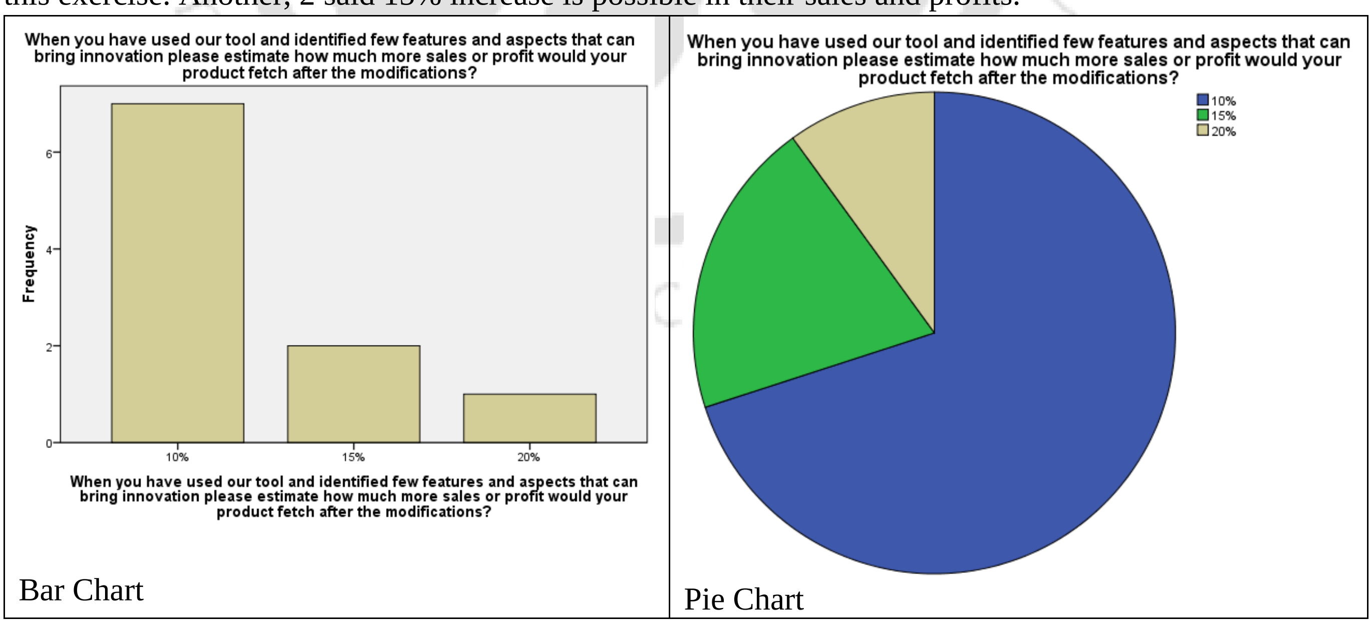


Figure 6.10: % of profit after modification

Q.9. In your opinion do MSMEs require such methods and if so, are you willing to procure one if it is made available commercially with a number of features?

The majority of responses (6) agreed that MSMEs require such methods and if they are made available commercially with added features, they will be willing to procure one and 4 strongly agreed for the same.

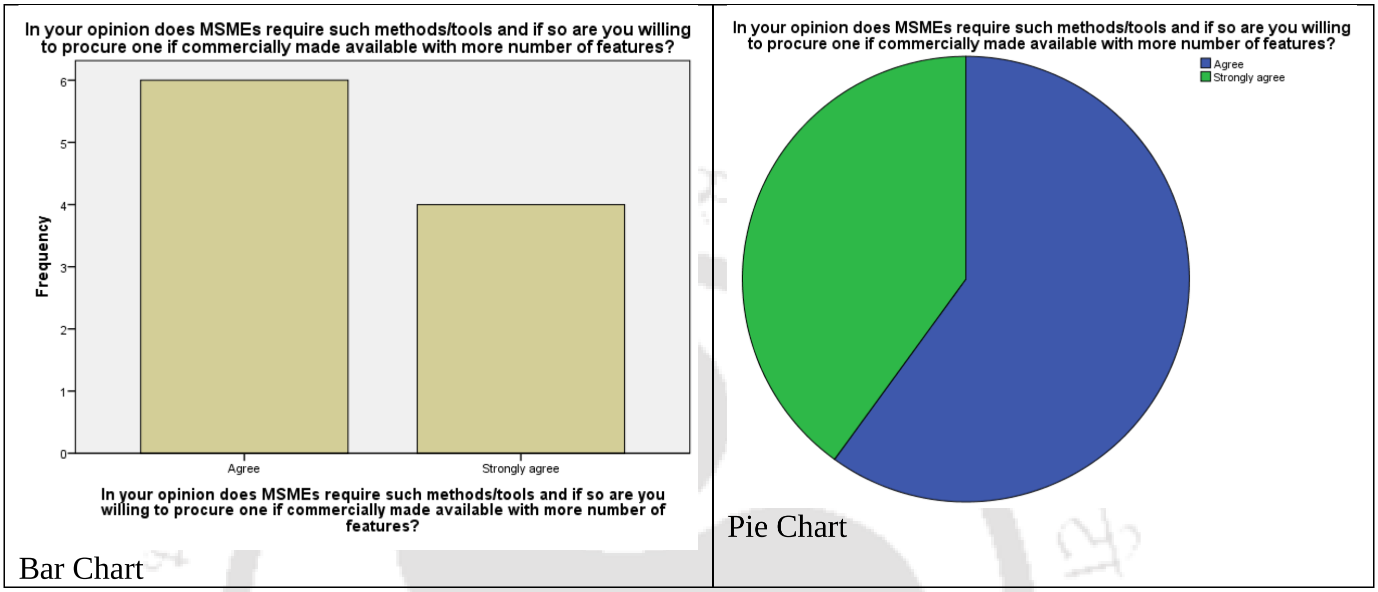


Figure 6.11: Need of such tool

Q.10. What is the level of satisfaction while using our method?

The majority of responses (9) were very satisfied using our method and it helped in improving their products with the remaining that were 1 extremely satisfied.

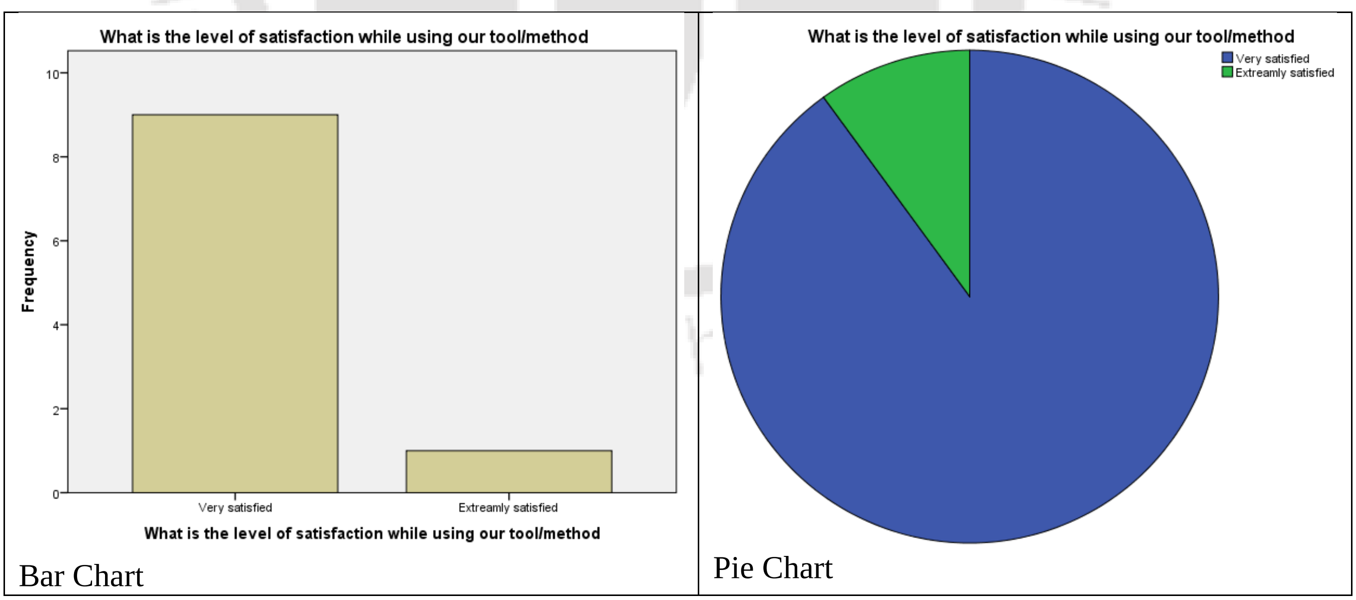
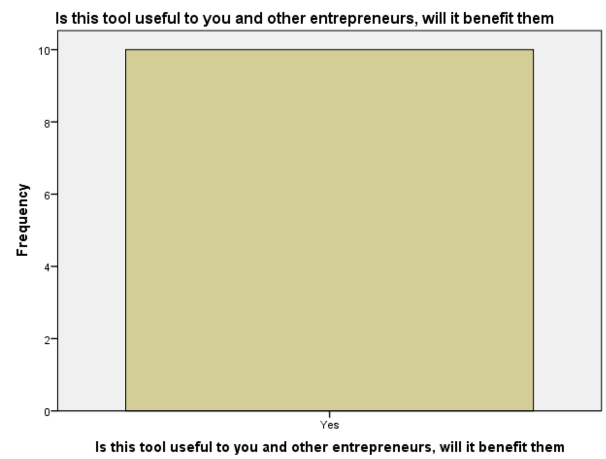
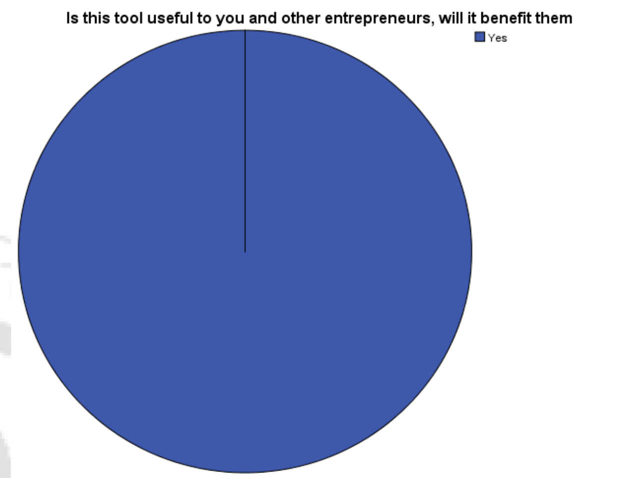


Figure 6.12: Level of satisfaction

Q.11. Is this frame work /tool useful to you and other entrepreneurs, will it benefit them?
10 of survey, responded saying our frame work /tool is useful to them and other entrepreneurs and it will definitely benefit them.



Bar Chart



Pie Chart

Figure 6.13: Beneficial to other entrepreneurs

12.When you were undergoing this exercise, which aspects of this frame work or tool impressed you the most?

All the 10 respondents were positively inclined towards the linkograph method as it highlighted the spots for improvement, when compared with other product or competitor's product. The graph method was also not technically complex.

6.4 Inferences from the qualitative analysis

Based on the survey results we can infer that, the method and the frame work is working as per the present prerequisite of MSMEs. From the analysis and field study results it is observed that

- The method was found easy to use and effective by MSMEs.
- The method was doing what it is implied.
- It seems to be understood by MSMEs.
- It measures the steps in innovation as seen from linkograph results.
- Prioritization and concept selection became simpler for MSMEs.

The Final Validated frame work is as shown in Fig. 6.14

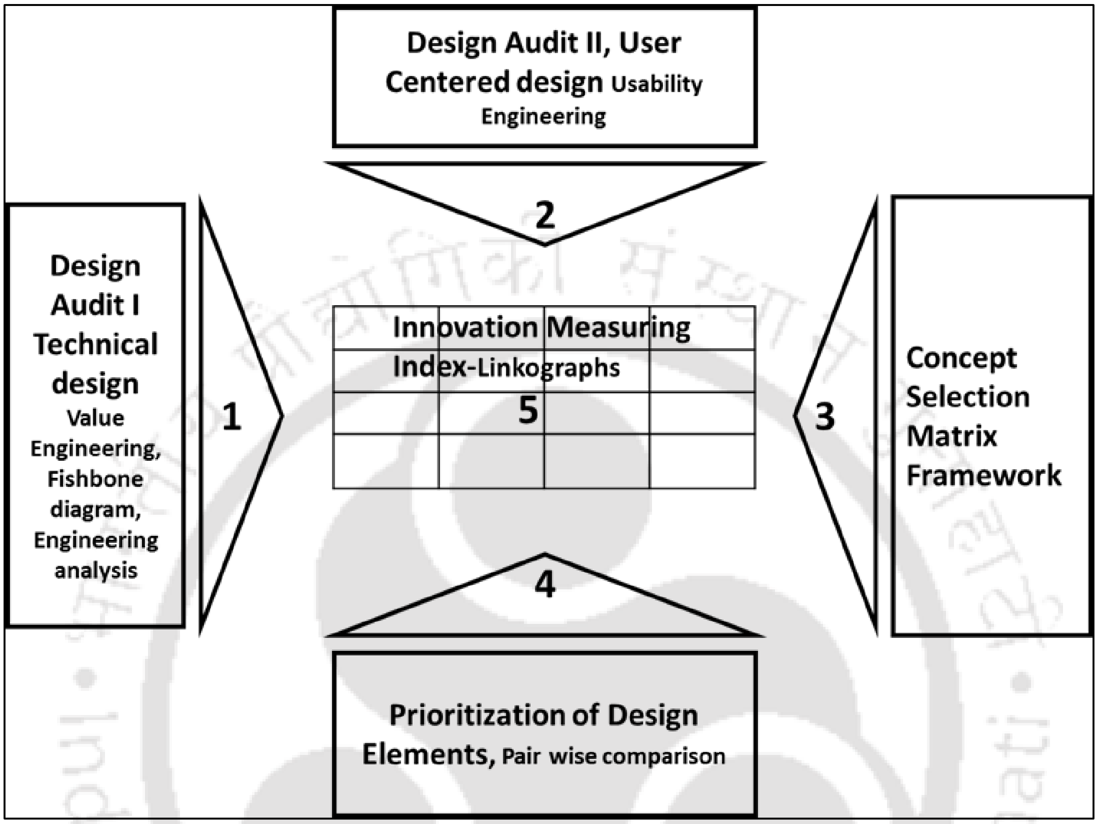


Figure 6.14: Final validated frame work (based on 10 MSME responses)

Summary of chapter 6: In this chapter detailed qualitative analysis results are furnished in order to validate the developed frame work. One case study results are reproduced and discussed how, the developed frame work gives the innovation index between the two similar products. Based on the 10 MSMEs visited a qualitative analysis results have been discussed. Conclusion and contribution of the thesis are discussed in the next chapter.

Chapter 7

7. Final developed frame work for innovation and conclusions

Abstract: In the previous chapter the developed frame work was validated. Chapter 7 highlights the contributions of the research in both practical and theoretical ways and enlists the future scope. The bird's eye view of the research question and findings are highlighted. Also, the limitations of the research have been discussed at the end of this chapter.

7.1 Final developed frame work

The following Fig. 7.1 is the developed frame work for innovation. Based on the experiments conducted the frame work has been developed based on our hypothesis i.e. characteristic of an innovation template which will also incorporate differential improvements as a measure of innovation (Metrics).

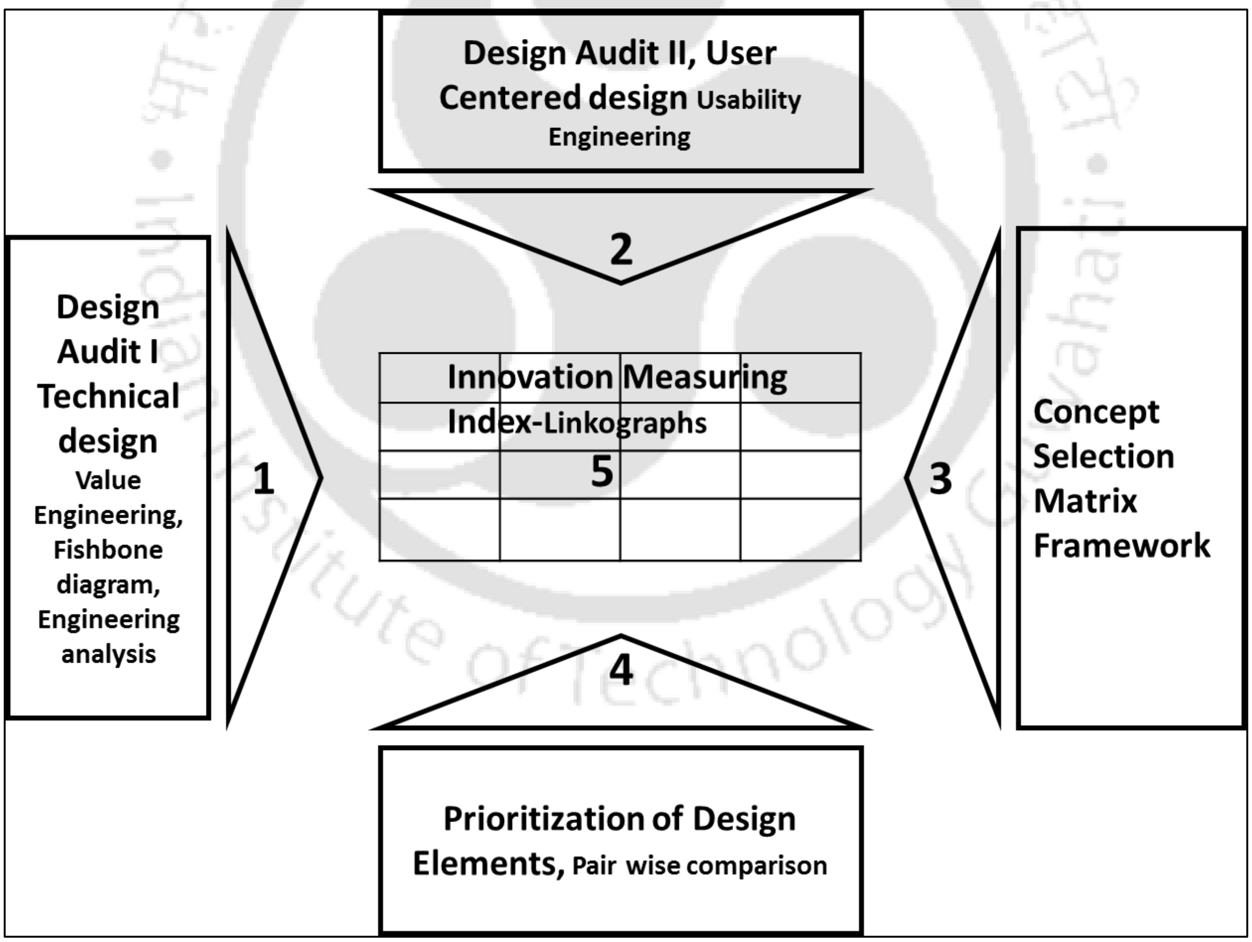


Figure 7.1: Final proposed innovation metrics frame work developed

7.2 Consolidated tasks completed

- Finding the gaps/areas in the MSMEs where they can bring innovation in their practices.
- Identifying the design elements which contribute more to aid innovation in products, at design phase specially in case of MSMEs.
- A readymade chart is developed for consideration of the designers where the design elements are prioritized, with each of the design elements having a percentage weight and rankings based on the experiments conducted.
- Proposed a matrix for concept selection during the design stage.
- Developed a guideline for the product analysis/design audit.
- Developed a method to measure innovation index for a set of products i.e. developed a scale for finding relative innovation index.
- Morphology for achieving innovation for MSMEs in Indian context.

7.3 Summing up the research output

In section 3.3, chapter 3, revisiting to the framed research questions

> **RQ1**. Can the MSMEs be provided with a practice methodology, using which they can add value to their products through knowledge of designing?
>
> **RQ2**.What are the current practices and levels of innovation practices in MSMEs, are they proficient and beneficial?
>
> **RQ3**. How to select product concepts that have higher innovation content while they are conceptualized during their designing phase?
>
> **RQ4**. Can we develop a comprehensive framework which can potentially develop into a model for achieving, comparing and indexing innovation during a product's design phase for the use by MSMEs in-house without the need of outsourced expertise?

For each research question we are collating the inferences and findings in order to summate as a bird's eye view of the thesis.

RQ1: What are the design elements that designer/MSMEs need to consider while in product design phase to cater innovation?

It started with design space theory and formulated 'novel fractal triangle' of innovation having all the elements that influence innovation.

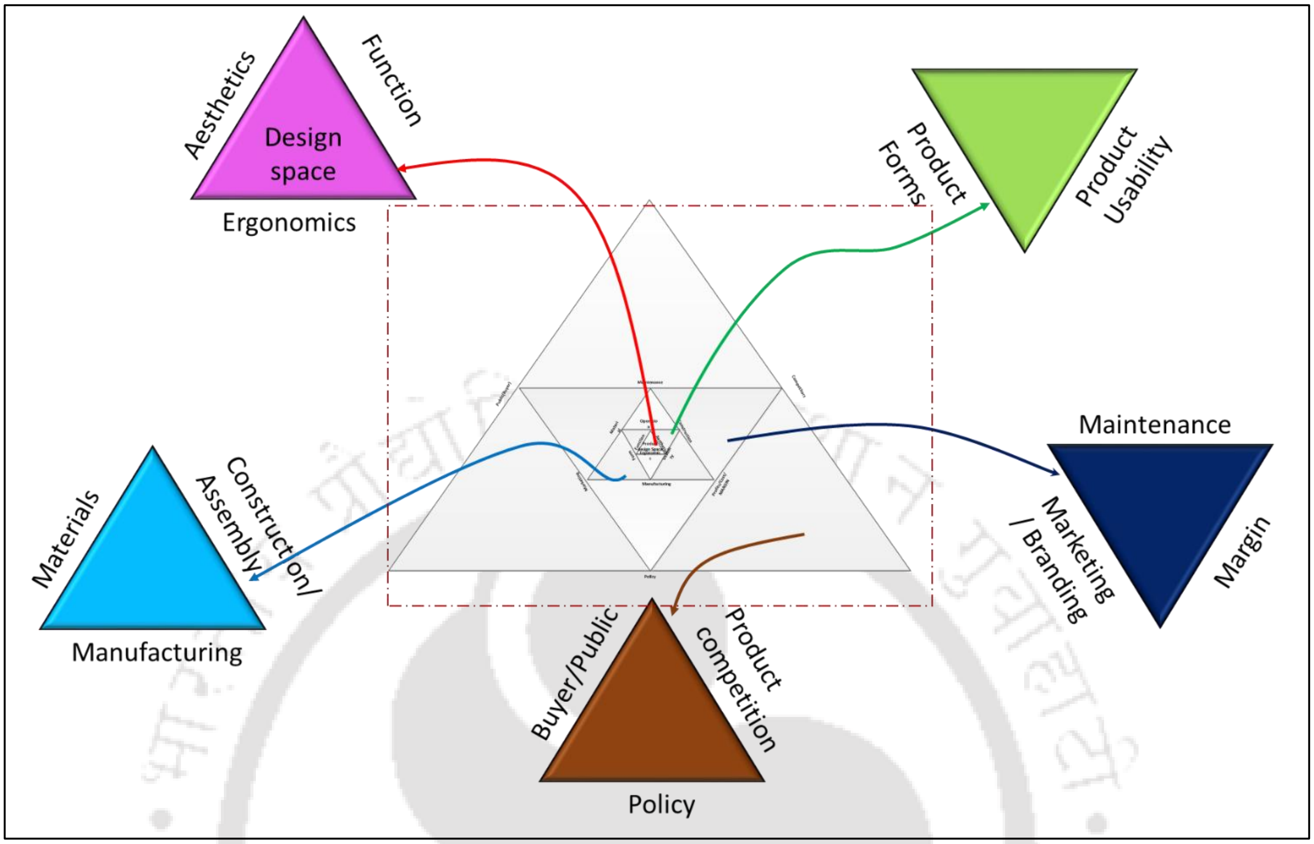


Figure 7.2: Reproduced from Fig 4.7, Chapter 4

RQ2: What are the current levels of innovation practices in MSMEs, are they sufficient and beneficial as compared to the other countries?

Based on the literature study and available innovation measurement, the models and reports lead to state of the art MSMEs.

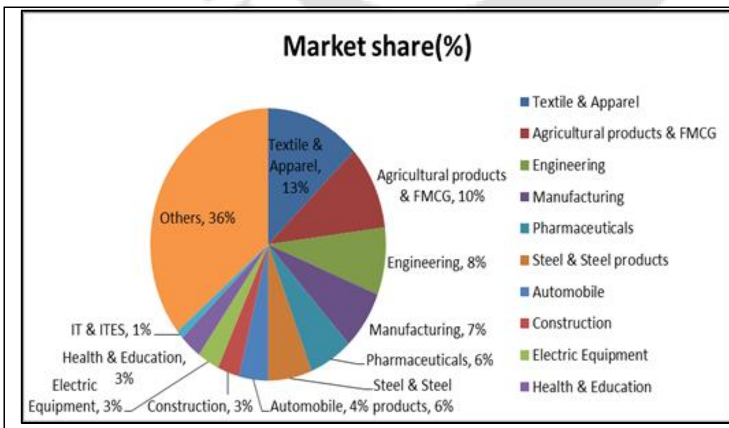


Figure 7.3: Reproduced from Fig 1.3, Chapter 1

Global Innovation Index

Rank In	**2018**	**2017**	**2016**	**2015**
Switzerland	1	1	1	1
United kingdom	4	5	3	2
United states	6	4	4	5
Hong Kong	14	16	14	11
Israel	11	17	21	22
China	17	22	25	29
India	57	66	60	81

Figure 7.4: Reproduced from Table 1.1, Chapter 1

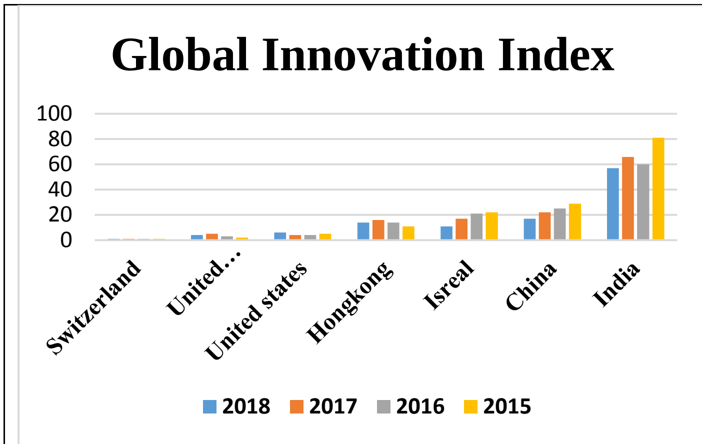


Figure 7.5: Reproduced from Fig 1.2, Chapter 1

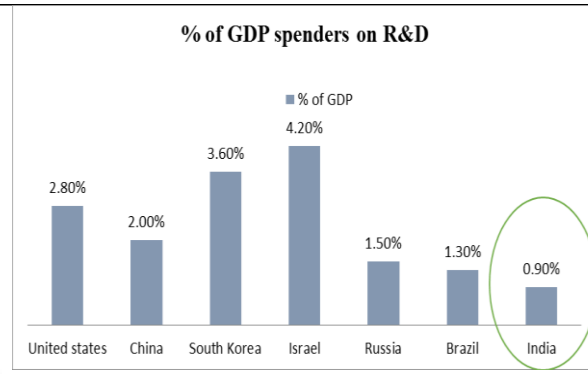


Figure 7.6: Reproduced from Fig 1.1, Chapter 1

RQ 2a. How and which methodology to carry out product analysis during design audit?

The methodology was developed as templates so that MSMEs could easily follow and identify the innovation spots. Based on the following method, pilot studies have been conducted and the main experiments were carried out on similar lines.

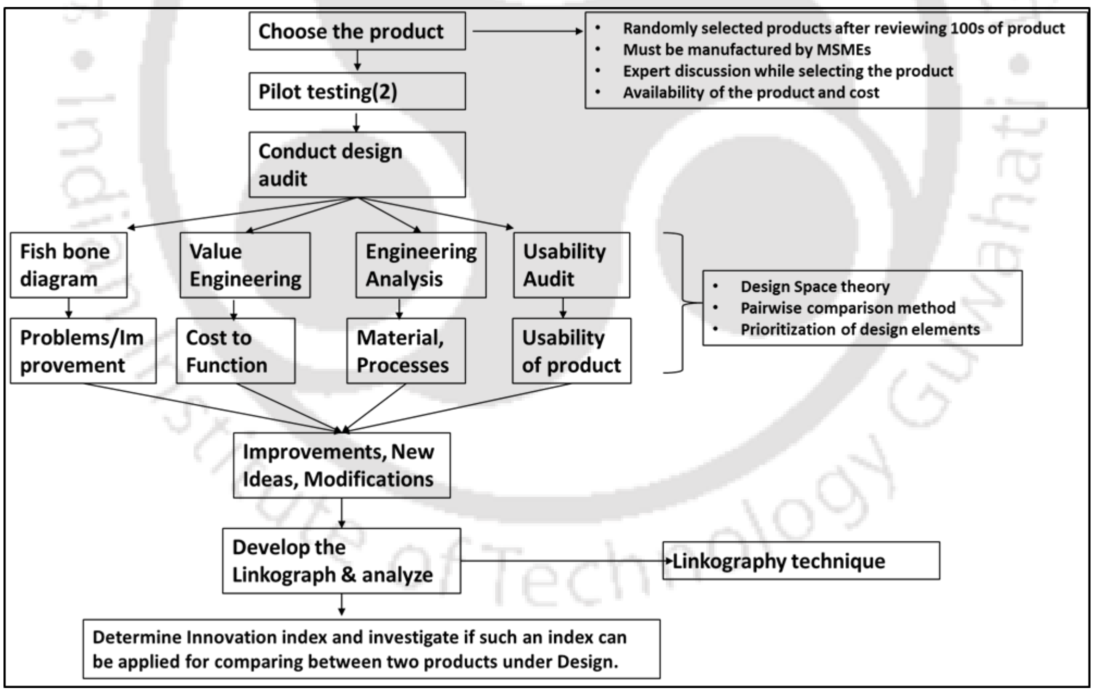


Figure 7.7: Reproduced from Fig 3.5, Chapter 3

RQ3: How to select the concepts generated during designing phase?

We have developed simple and easy to use framework for concept selection during the design phase.

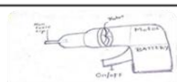
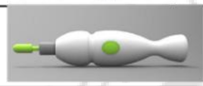
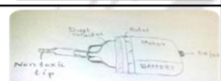
		Design Methods Applied	Degree of newness		Design Criteria (strong=9; medium=3; weak=1)								Sheer Innovation Prospect	Rank
				Criterion weightage	9	9	9	9	9	9	3	3		
Problem 1: Ear wax remover					Low Cost	Light Weight	Efficiency	Functionality	Good ergonomics	Ease of use	Maintenance	Less process time		
Case 1														
Design1		Brain storming	3		3	3	9	9	3	9	3	9	360*3	2
Design 2		SCAMPER	3		9	3	9	3	9	9	9	9	432*3	1
Design 3		SCAMPER, linkograph	1		1	9	3	3	9	3	3	3	270*3	3

Figure 7.8: Reproduced Table 4.16, Chapter 4

RQ 4: Can we develop a framework for achieving innovation during product design phase?

As a hypothesis we developed and validated the proposed innovation frame work metrics for MSMEs.

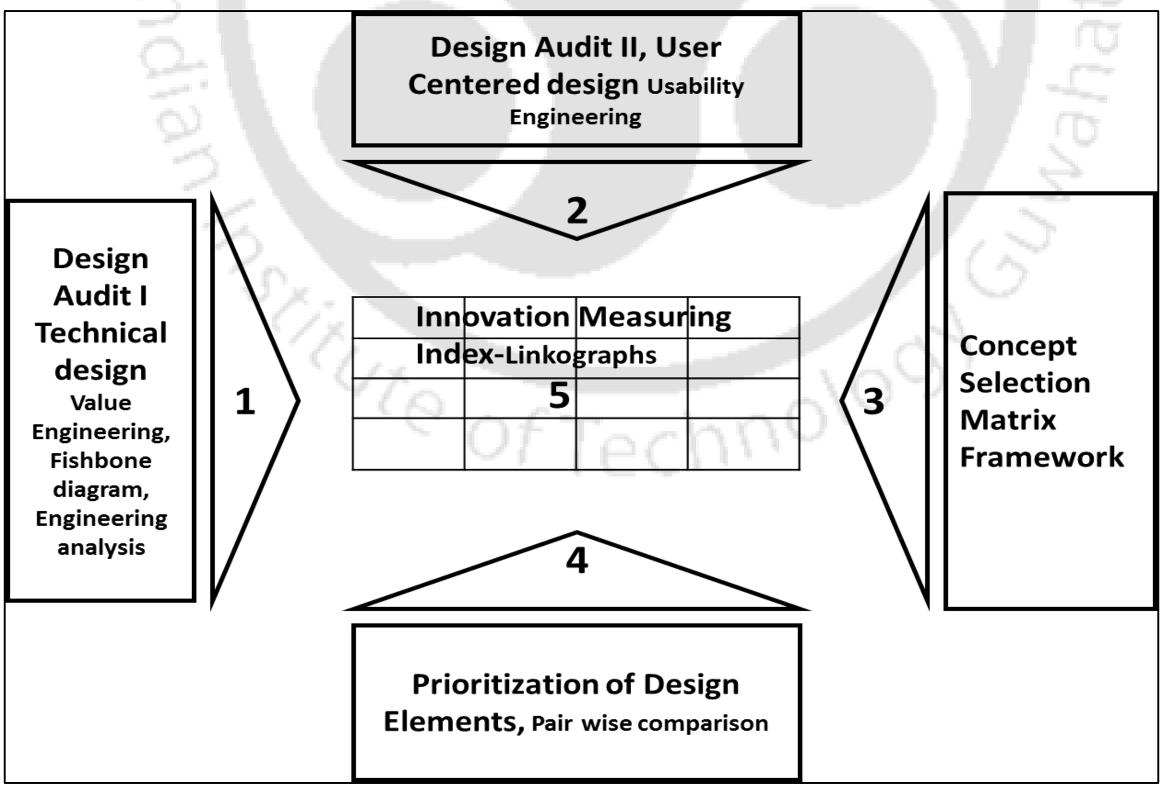
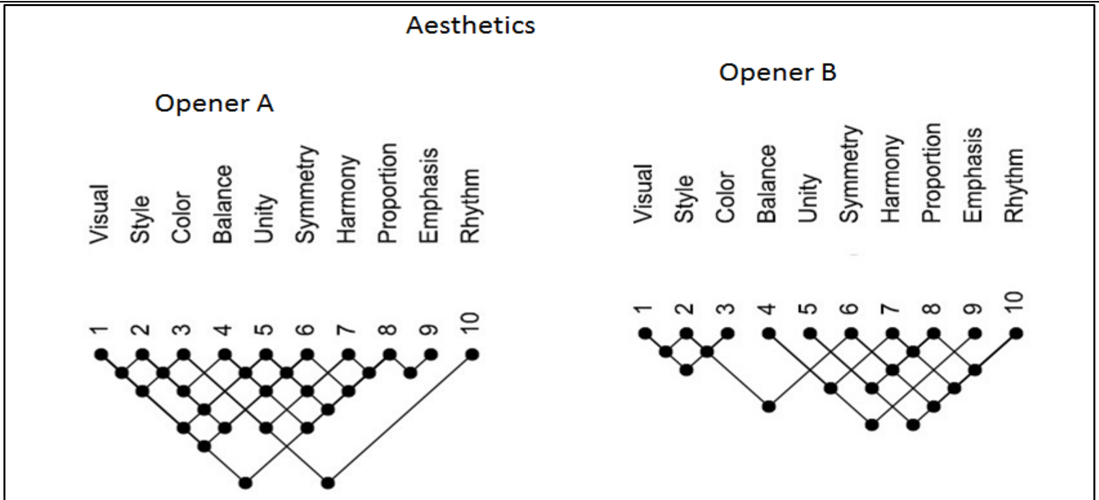


Figure 7.9: Reproduced from Fig 7.1 Chapter 7

RQ 4a How such framework will give relative innovation index amongst the given set of products of same family?

We can measure the innovation differential in terms of link index.



	No of Moves N	Link Index LI	%CM 2	%CM3	%CM4	%CM5	%CM6
Product A	10	2		30	20	10	
Product B	10	1.4		10	10		

Figure 7.10: Reproduced from Fig 5.11, Chapter 5

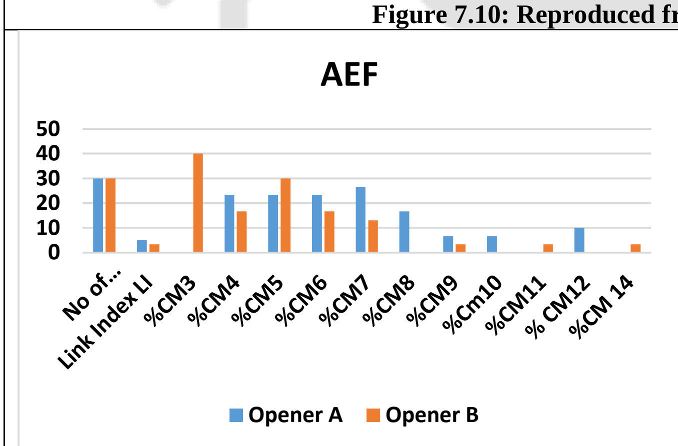


Figure 7.11: Reproduced from Fig 5.19, Chapter 5

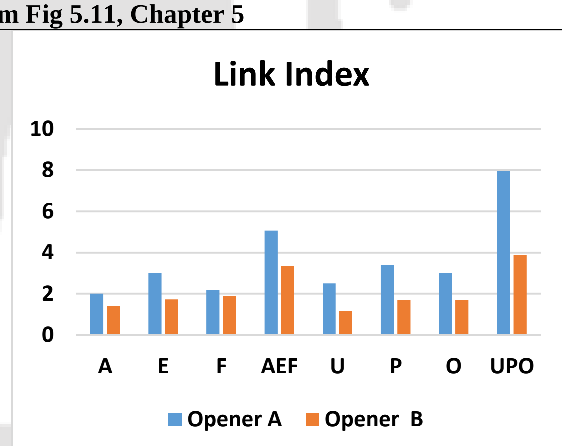


Figure 7.12: Reproduced from Fig 5.21, Chapter 5

7.4 Summary of Contribution in the thesis

The work in this thesis concentrates in the area of product design. It dealt with MSMEs and developed an index for Innovation. Due to the lack of the design thinking and gap in the knowledge base many MSMEs are not able to innovate even though they are capable of achieving it. As seen from the literature not much is developed with reference to methods, tools and techniques in order to bring innovation. Measuring innovation at organization/system level is known, but measuring innovation at the product level w.r.t MSMEs is not available. This research studies the problems faced by MSMEs and practices they follow, and comes up with a new simple method for measuring innovation at the product level. Aiding innovation by the design elements prioritization is done along with concept selection matrix and a new technique to measure relative innovation index has been proposed.

The research carried out is a novel method in product designing application and measurement of innovation for MSMEs. It adds to the knowledge-base, through which value addition has occurred in micro steps during design phase, and this can be tracked. This research is able to identify the parameters influencing innovation in the product. The Linkographs for small products have been developed, using the design elements to measure relative innovation index of given similar products.

7.5 Limitations of the research

The case studies considered in this research are based on everyday simple products manufactured by MSMEs. They are randomly chosen and the methods applicability in the case of complex products consisting of hundreds of parts has not been examined. Therefore, the inferences are confined to small utility articles. The sample size of 9 case products is a small size and one can expand it to a larger sample size and bigger assembly products. The survey for validating the frame work was limited to ten and more varieties of MSMEs can be included. The MSMEs cooperation is very crucial, but many MSME owners and engineers who were approached were reluctant in sharing their views, time and practices with the researcher there by limiting the validation survey to ten samples. The linkography is a cognitive technique and developing the linkographs captures the thinking process of the mind. However, there was difficulty to explain the concept to some of the MSME respondents, and it required repetitions.

7.6 Future scope of work

From fractal triangle of innovation up to second level, design elements were considered in this thesis. The future work could be extended to third level, fourth level and fifth level. One can develop a decision making tool of advanced level, so that our entire study can be used as a tool or excel sheet or program to directly process the innovation index as a computational output. Optimization technique can be used to cross check or refine the product concepts selected.

Summary of chapter 7: This chapter provides the summary of consolidated findings, tasks completed summating up the research questions with their findings, important outcomes, recommendations, along with contribution of thesis. Future scope and limitations of the current study have been presented.

Appendix A

Questionnaire for MSME personnel: Content Analysis

Dear Sir/madam,

This is a survey to find out how effective is our frame work? We have developed a frame work, what it does is:

- Makes product design steps in easy way with value addition to the product when compared with the competitor's product.
- It gives the areas of improvement when product analysis is done (which includes a fish bone diagram, value engineering, engineering analysis and usability test).
- Also plotting the linkographs leads to measure the relative innovation index for the given set of products with exact locations of improvement in the products.

This frame work has been developed specifically for MSMEs, we want your opinions, views and suggestions for improvements. We want your evaluation and usefulness of this frame work. It is our pleasure to take this opportunity to reach you all through this questionnaire. I hope with the expert knowledge this project would be successful. We will record your participation for the experiment in terms of photos, interviews, etc. The gathered information will be used as part of our research. However, personal information such as name and photo will not be revealed. We thank you for your valuable time and giving feedback regarding our research.

Company Name:

Products:

Turn over yearly:

Customers:

Name:

Gender: Male Female

Age Group:

Designation:

Part A

Questionnaire

1. Can you describe how you design a product?

2. Do you follow any procedure for the development of products in your organization? If so, what it the procedure?

3. How do you get ideas for designing products?

4. Of the products that you manufacture which of the product is designed in house?

5. For the above product, what is the methodology used by you? Please describe it briefly.

6. Do you involve technical people in the development of the product?

Yes **No**

7. How do you manage to document the design aspects and design issues, procedures with your product?

8. From the series of products, you manufacture can you identify few innovative features that you think you are providing, which your competitor does not possess?

9. When you opted for a new design, how did you handle the complaints from the user? And how did you come up with a solution?

In house or Outsource

10. Have you heard these terms Aesthetics, Ergonomics, Function, Usability, Process innovation, and Optimization?

Yes **No**

If so how do you make use of them in your organization, please specify:

11. Who decides on the design features of your product and on what basis did you decide?

Questionnaire regarding our method: Qualitative analysis

1. Would you identify the innovation capabilities of our method?
Yes No

2. What is the amount of innovation that can be raised and where can it be incorporated?
10% 15% 20% 50% 100%

3. How much more value can be added in terms of innovation?
5% 10% 20% 50% 100%

4. Do you think we can use this tool for coming up with a completely new product?
Yes No

5. How well will it (our method) do to meet your needs?
a] Extremely well b] Very well c] Somewhat well d] Not so well e] Not at all well

6. How likely are you going to practice our method of measuring innovation relatively?
a] Extremely likely b] Very likely c] Somewhat likely d] Not so likely e] Not at all likely

7. By using our model are you, now in a position to identify the difference between your product and the competitor's product?
a] Strongly agree b] Agree c] Neutral d] Disagree e] Strongly disagree

8. When you have used our tool and identified a few features and aspects that can bring innovation, please estimate how much sales or profit would your product fetch after the modifications?
5% 10% 20% 50% 100%

9. In your opinion do MSMEs require such method and if so, are you willing to procure one if it is made available commercially with a number of features?
a] Strongly agree b] Agree c] Neutral d] Disagree e] Strongly disagree

10. What is the level of satisfaction while using our method?
a] Extremely satisfied b] Very satisfied c] Unsure d] Slightly satisfied e] Not at all satisfied

11. Is this method useful to you and other entrepreneurs, will it benefit them?
Yes No

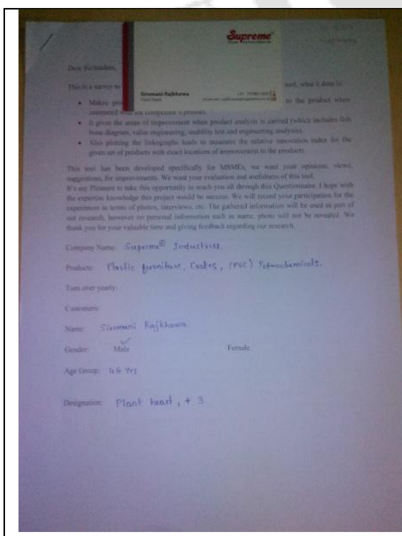
12. Which aspect of the tool requires more improvements, are there any issues and factors that you wish to add to our tool?
Or when you were undergoing this exercise, which aspects of this model or tool impressed you the most?

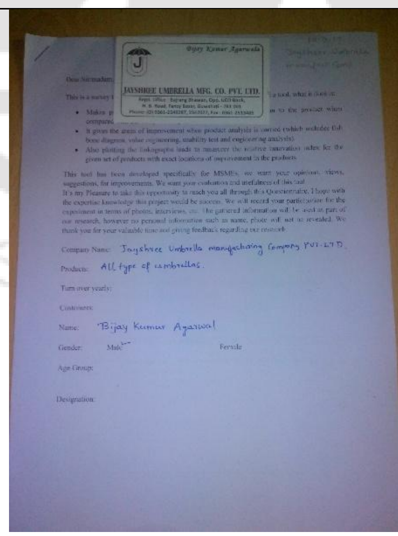
Linkograph	**Value engineering**	**Usability test**	**FBD**

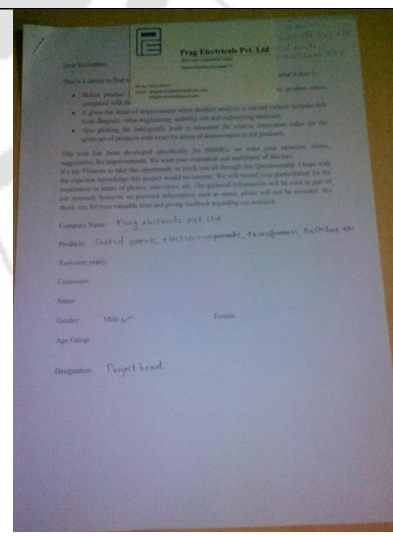
13. **In general, what is your understanding and view on the word innovation?**

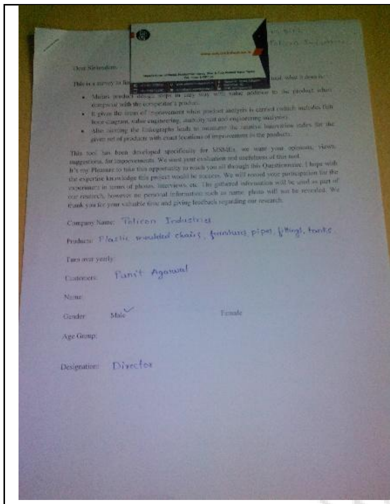
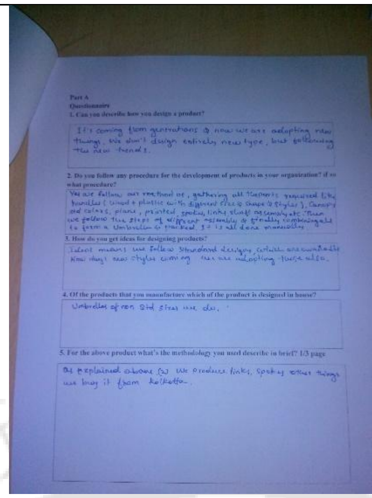
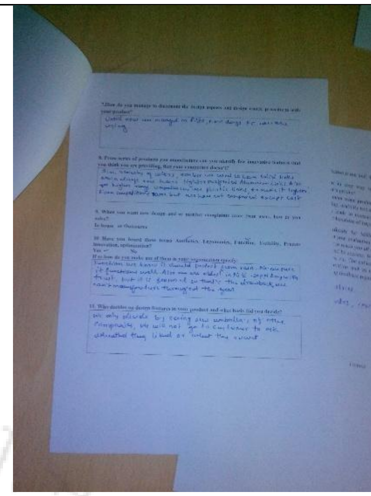
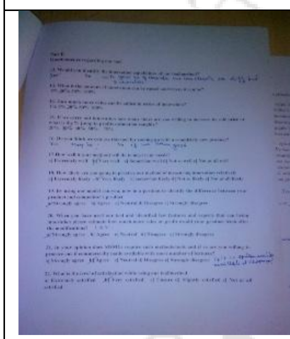
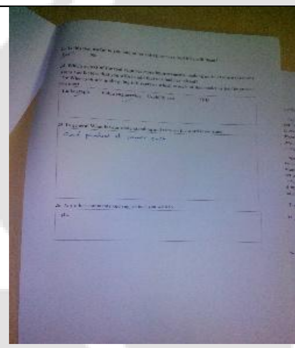
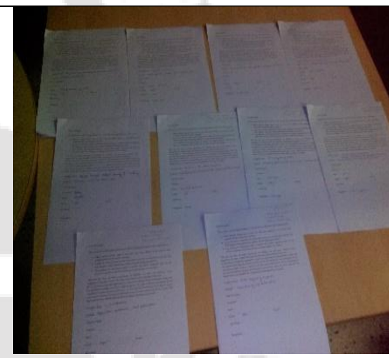
14. Any other comments and suggestions you wish to share

Survey forms filled by MSMEs







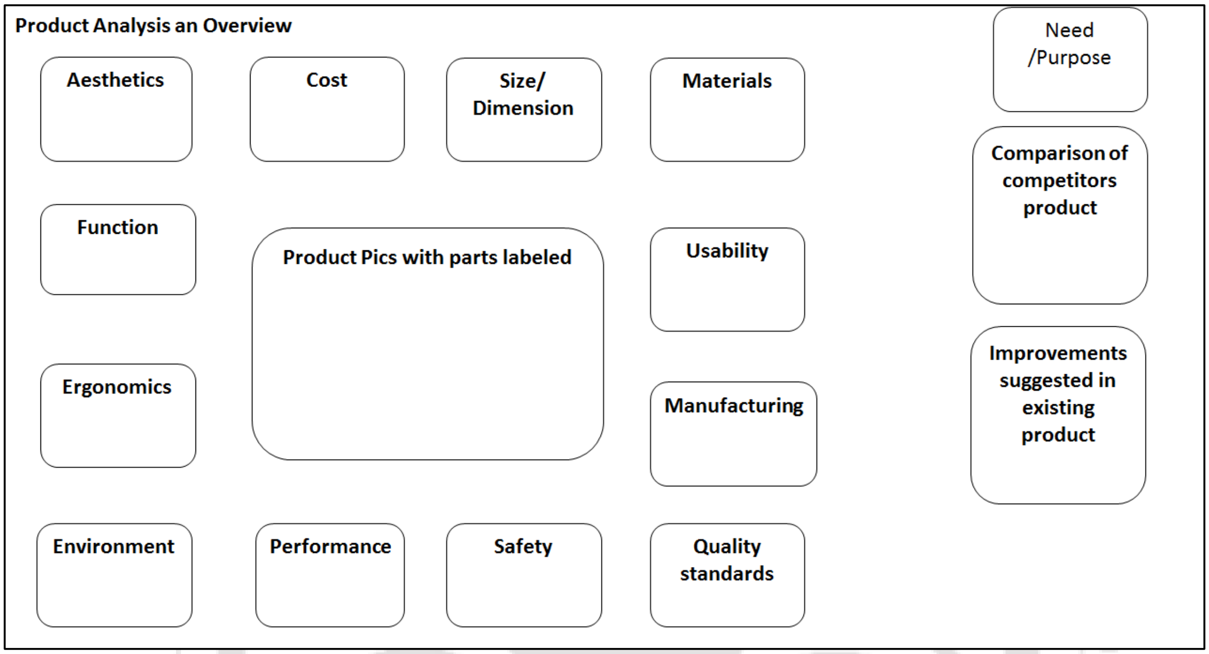
		
		

Photographs of MSMEs during the survey

Appendix B

Templates developed for survey while in prioritization of design elements, Usability testing and product survey

B.1.Elements conisdered in user survey



B.2 Aesthetics

Aesthetics
What does it resemble?
What shape it is?
Are the looks suitable to the user?

Rate the product based on following parameters affecting the Aesthetics

	5	4	3	2	1	Total
Visual						
Style						
Color						
Balance						
Unity						
Symmetry						
Harmony						
Proportion						
Emphasis						
Rhythm						

B.3. Usability

Rate the product based on following parameters affecting the Usability

Usability

- Is it effective while using?
- Is it efficient?
- Is it best suited for its work/task/function?
- Is easy to learn?

	5	4	3	2	1	Total
Effective						
Efficient						
Engaging						
Error tolerant						
Easy to learn						

B.4.Function

Rate the product based on following parameters affecting the Function

Function

- What does it do?
- How does it work?
- What inputs are there(parts buttons, sensors etc.)?
- What are the outputs light, sound, nature of work
- What is the main function of the product
- How well does this product do the work?
- Primary & secondary function ?

	5	4	3	2	1	Total
Safety						
Efficiency						
Cost						
Need						
User friendly						
Value						
Features						
Durability						
Strength						
Construction						
Stability						

B.5.Ergonomics

Rate the product based on following parameters affecting the Ergonomics

Ergonomics

- **Is the product Ergonomically designed?**
- **Is it having proper grip?**
- **Is designed for Indians based on Anthropometry data?**
- **Is it causing any stress while using?**

	5	4	3	2	1	Total
Repetition						
Reachability						
Duration						
Force						
Posture						
Anthropometry						
Visibility						
Direction						
Glance						
Grip						

Assignment: Product Analysis and Measuring innovation index(Metrics)

Time: One week

Problem: Given the product and given the templates and metrics, along with instructions given to you, find the innovation index of the product. Suggest newer design that you redesign. Attach all the sheets and submit the same.

1. Opener example full explanation 2. Umbrella for class example

3. Ear wax remover, 4. Solar powered air vent cooler for car, 5 Chairs(Plastic)

Value engineering

Sl No	No of Parts	Component	Function	Noun/Verb	Importance to **user**	Cost in Rs	%	Need of alteration and reason	Priority of redesign
1									
2									
3									

Usability testing

Parameter	**Details**	**Remarks/Problems**
Product Identification		
User Identification		
Environment	Workspace Work surface	
Effectiveness to use Functional	Features	

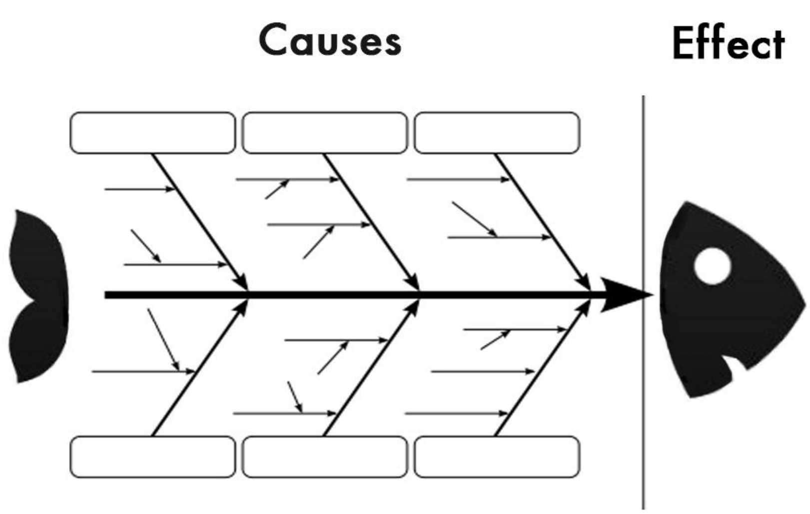
	Limitation Consequences	
Efficiency to use Efficient	Usable	
Error free in use Safe	Safety	
Easy to use Friendly	User-friendly	
Enjoyable in use Pleasurable	User Experience	

Engineering analysis

Sl No	Parts	Weight/ Dimensions	Figures	Material	Process	Fixed costs	Variable costs	Volume	Total Unit Cost in Rs
1									
2									
3									

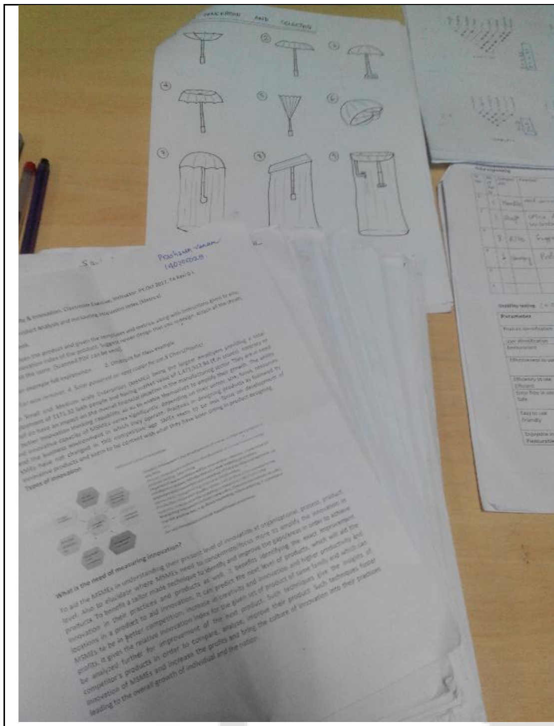
Fish bone diagram

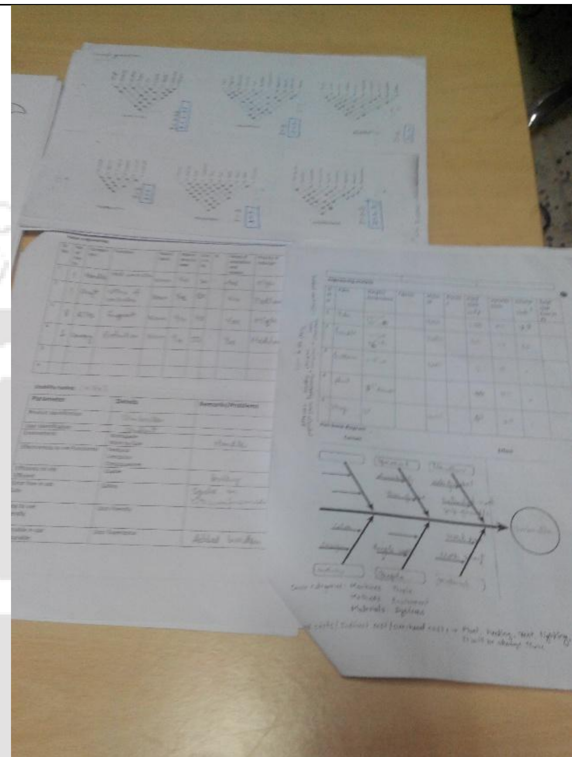
Causes **Effect**

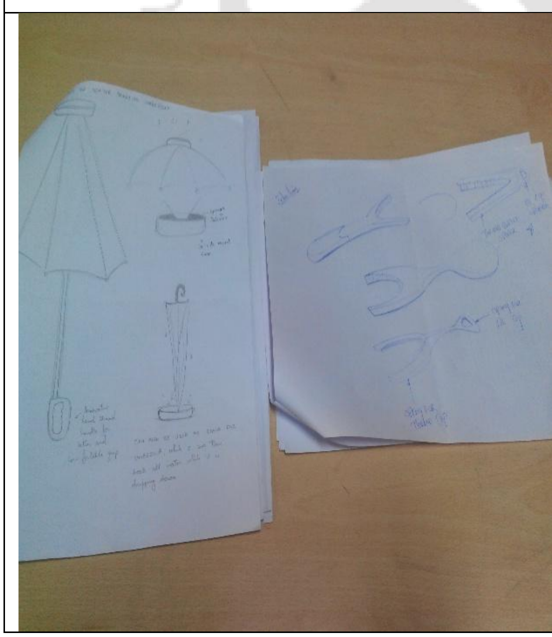


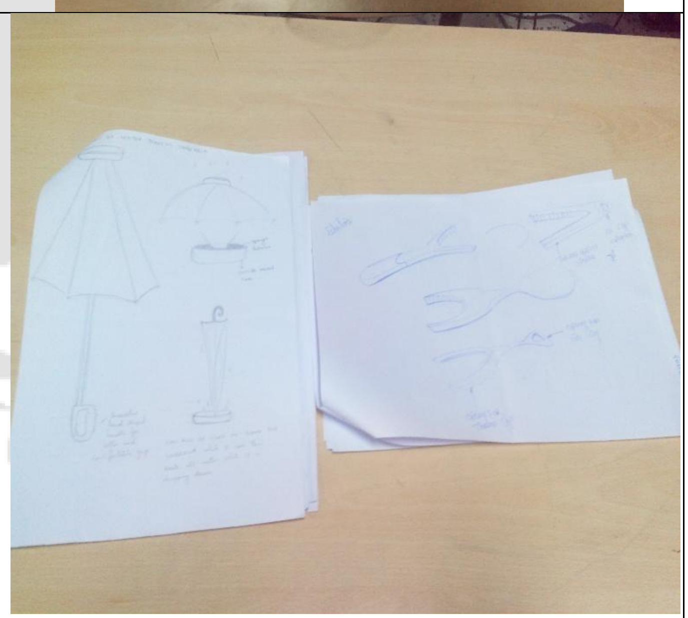
Assignment Images

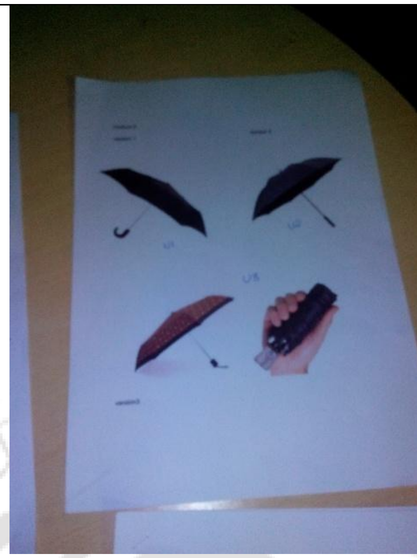
Assignment was given to the professionally trained design students (30). Templates were given and after showing the products feedback was recorded. Below images show some feedbacks.

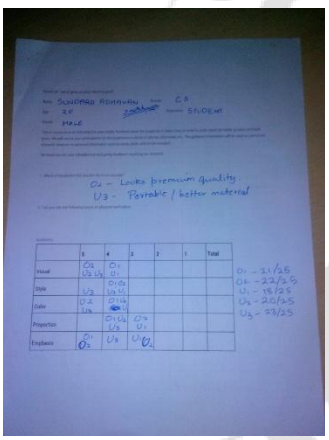


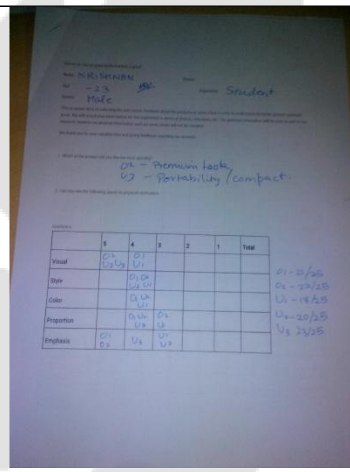












Appendix C

Mapping of ISO standards with design space theory and other elements

From our case studies, we are able to measure the innovation index between the products. Using linkographs we can measure the innovativeness of the product. This phase of analysis, linkographs leads to the gaps of improvements through the links. If the link index is raised to the value 1 as highest, then the product will be of the same level of innovation index. All the products taken for analysis were innovative since they had greater features, cost effective etc. We can also develop a next product from the same family of products. This product will have more value additions. The concepts and concept selection matrix provides the weightages for the identified criteria and rankings can be calculated to finalize the next level of product. Innovativeness of a product can be checked by plotting and calculating link index.

We have carried out individual calculations for aesthetics, function, ergonomics, processes, operations and usability to check for value addition in these products. Of course through material, operations and processes we can add value and at the same time user centered features or user pushed features and usability also add value to the product. Therefore, making it innovative.

When we talk of usability or user centered design there are certain ISO standards like ISO 9241, ISO 13407, along with standard literature. These need to be considered in a user centered design. Some important ISO standards are efficiency, effectiveness, satisfaction, memorability, security, universality, productivity, and context of use and goal.

In our study, we have already identified and prioritized design elements. At the micro level we are mapping these design elements with the ISO standards, in order to identify the overall effect of usability on the innovation. It becomes a challenging task for the users since it is complex for mapping. Hence, it is carried out by the researcher as an expert.

In understanding the mapping, ISO standards and design elements are plotted as shown in **Fig C1** by asking relevant questions like in aesthetics, visual, style, color, etc. Does the visual element increase efficiency? If yes a point is added, and the same is repeated for all the elements. Now that we have mapped all the elements with corresponding weights, let us take our cases in which an already more innovative product is identified through the linkographs and link index. The ratings are done based on the mapped weights which gives the value operands of design space as shown in **Table C1.**

From the design space theory, we have the ideal product value as 1, which does not exist and is in the Product Proximity Zone 1 (PPF1). Moving outwards will be PPF zone 2, PPF zone 3, PPF zone 4, respectively. From the mapping we have Product 1 (umbrella) as 0.89 (A: E: F ratio).

Considering our products and cases, it is observed that all of them fall under PPF zone 3 and their values lie in the range of 0.8 to 0.899. The zone 1 is 1 so PPF zone 2 will be in the range of 0.9 to 0.999 as shown in **Fig. C2.**

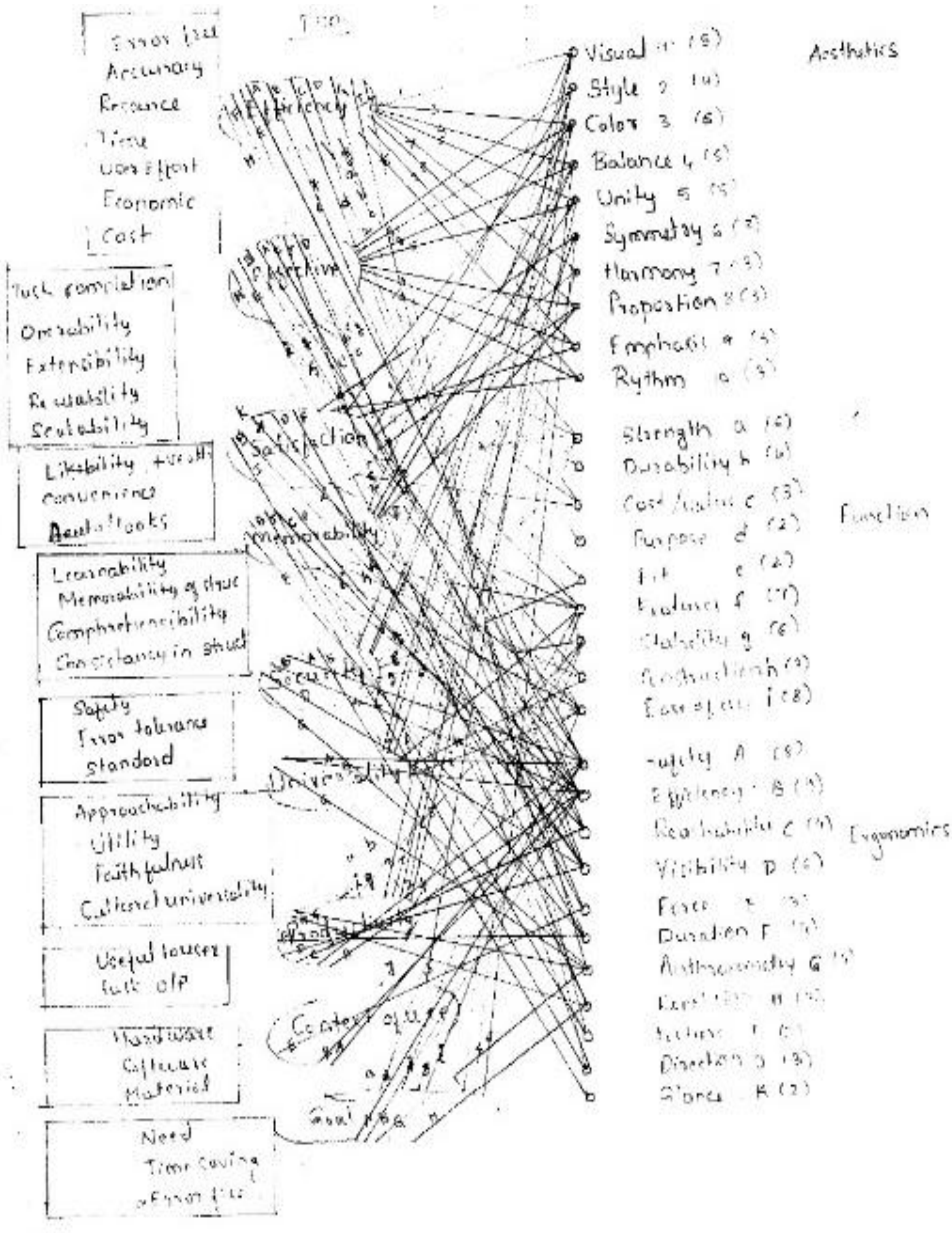


Figure C1: Hand drawn mapping of ISO standard with the design elements

Mapping of ISO Standards with design elements collating the results

Table C1: Design elements and their ratings

Aesthetics	Function	Ergonomics
Visual (5)	Strength (6)	Safety (8)
Style (5)	Durability (4)	Efficiency (9)
Color (4)	Cost/Value (3)	Reachability (4)
Balance (5)	Purpose (2)	Visibility (6)
Unity (5)	Fit (2)	Force (3)
Symmetry (3)	Features (7)	Duration (4)
Harmony (3)	Stability (6)	Anthropometry (4)
Proportion (3)	Construction (3)	Repetition (3)
Emphasis (3)	Ease of use (8)	Posture (2)
Rhythm (3)		Direction (3)
		Glance (2)

Table C2: Represents the contribution of design elements in ISO standard after mapping

Product 1: Umbrella

Aesthetics	Function	Ergonomics
V-3	S-4	S-6
S-4	D-3	E-6
C-5	C-2	R-3
B-4	P-2	V-4
U-2	F-1	F-2
S-2	FE-4	D-2
H-2	S-4	A-2
P-2	C-1	R-3
E-2	E-5	P-2
R-2		D-2
		G-2
=28 (0.28%)	=26 (0.27%)	=34 (.34%)

Product 2: Opener

Aesthetics	Function	Ergonomics
V-4	S-5	S-6
S-4	D-3	E-6
C-3	C-3	R-4
B-5	P-2	V-4
U-5	F-2	F-2
S-2	FE-5	D-1
H-2	S-4	A-3
P-2	C-2	R-0
E-2	E-5	P-0
R-2		D-2
		G-0
=31 (0.31%)	=31 (0.31%)	=28 (0.28%)

Product 3: Envelope

Aesthetics	Function	Ergonomics
V-4	S-5	S-5
S-4	D-4	E-6
C-3	C-2	R-3
B-5	P-2	V-4
U-5	F-2	F-1
S-2	FE-6	D-1
H-2	S-3	A-2
P-1	C-2	R-2
E-1	E-6	P-0
R-1		D-0
		G-0
=28 (0.28%)	=32 (0.32%)	=24 (0.24%)

Product 4: Vidyut laptop

Aesthetics	Function	Ergonomics
V-5	S-4	S-4
S-3	D-3	E-5
C-3	C-3	R-2
B-2	P-2	V-3
U-4	F-2	F-2
S-3	FE-6	D-3
H-2	S-4	A-1
P-2	C-2	R-2
E-1	E-6	P-0
R-2		D-1
		G-1
=27 (0.27%)	=32 (0.32%)	=24 (0.24%)

When these are plotted, our design triangle is as represented in the **Fig C2**. The calculated values of AEF are the edges of the triangle and all the values are less than 1.

Table C3: Values mapped on design space triangle

Product (Umbrella) 0.28 A, 0.34 E, 0.26 F 0.88<1	Product (Opener) 0.31 A, 0.28 E, 0.31 F 0.9<1
Product (Envelop) 0.28 A, 0.24 E, 0.32 F 0.84<1	Product (Vidyut laptop) 0.27 A, 0.24 E, 0.32 F 0.83<1

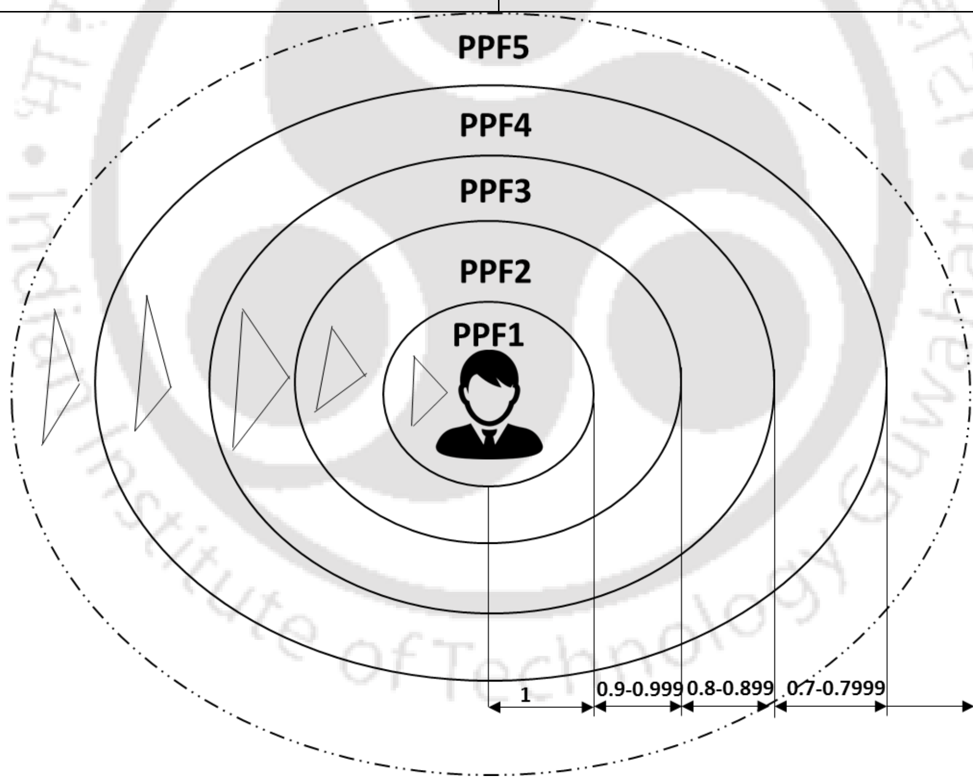


Figure C2: PPF zones and their limiting values

From the mapping of ISO standards with the design elements we infer the numbers effecting and their %. This is then used in the phase of design.

Table C4: Effect of design elements and their percentage

ISO standards	Total Effect on design elements	%
Efficiency	25	19.23
Effectiveness	21	16.15
Satisfaction	16	12.30
Memorability	12	9.23
Security	13	10
Universality	9	6.9
Productivity	17	13.07
Context of use	5	3.8
Goal	12	9.23

Here, the efficiency is connected with 25 design elements, effectiveness is connected with 21 elements, satisfaction is connected with 16 design elements and so on.

The ISO standards like ISO 9241, ISO 13407 need to be considered in a user centered design. Important ISO standards are efficiency, effectiveness, satisfaction, memorability, security, universality, productivity.

Memorability: The number of steps involved in accomplishing the task while using the product. These micro steps need to be remembered. Greater number of operations will require more attention in finishing the task. If opening of the umbrella is broken in to number of steps, after using the umbrella one has to follow the same steps in folding and keeping.

Security: Any product while in use, should give feeling of secure to the user. Product should be good enough to bring this feeling while in use.

Universality: The product should be designed in such a way that; it should be accepted by all type of users universally. It should work any were any place, and parts of the product should be available and replaceable.

Appendix D

Paper publications

Sl.No.	Authors	Year	Title	Complete Reference of Journal
1	Ravi Lingannavar, Pradeep Yammiyavar	2018	Product Innovation Index Using Linkograph Analysis	Accepted: ICoRD'19 International Conference on Research into Design Indian Institute of Science, Bangalore, 9-11 January, 2019.
2	Pradeep Yammiyavar, Ravi Lingannavar	2018	Analysis Using Linkograph to Identify Product Features for Innovation: A Human Centered Usability Engineering Approach	Advances in Ergonomics in Design, Proceedings of the AHFE 2018 International Conference on Ergonomics in Design, July 21–25, 2018, Loews Sapphire Falls Resort at Universal Studios, Orlando, Florida, USA, 123. AHFE 2018, AISC 777, pp. 359–369, 2019.
3	Ravi Lingannavar, Pradeep Yammiyavar	2017	A Review of Techniques for Indian Small Scale Industries in Effecting Innovation through Design	International Journal of Engineering Science and Technology. (ISSN 0975-5462, Vol 9, Issue 09, September 2017, pp 160 - 165).
4	Ravi Lingannavar, Sai Prasad Ojha, Pradeep Yammiyavar	2017	A matrix framework proposal for evaluating innovation criteria of a design process output during product conceptualization	In Proceedings of International Conference on Research into Design, ICoRD'2017, IIT Guwahati, Guwahati, Assam ***Best Paper Award, ICoRD 2017, IITG, Assam***
5	Ravi Lingannavar, Pradeep Yammiyavar	2016	A framework for innovation for the use by SMES	International Journal of Engineering Technology, Management and Applied Sciences. (ISSN: 2349-4476, ISBN: 978-81-932712-8-5),October 2016, Volume 4, Issue 10.
6	Ravi Lingannavar, Pradeep Yammiyavar	2016	Prioritization of design elements influencing innovation in product design	In Proceedings of Humanizing work, and work environment, HWWE 2016, Jalandhar.
7	Sai Prasad Ojha, Ravi Lingannavar, Pradeep Yammiyavar	2015	Scheme to implement tacit knowledge of craftsman into rapid prototypes	5TH International conference on PLMSS, Product life cycle modeling, Simulation and synthesis, BITS Pilani Hyderabad campus.15 th - 17th December 2015

References

A

Alam, M., & Dubey, S. (2014). Owner-Manager's Innovativeness and Its Relation to Innovation in Small Firms. ASCI Journal of Management, 44(1).

Amabile T (1982).: Social psychology of creativity: a consensual assessment technique. J Pers Soc Psychol 43(5):997–1013.

Andrew, J. P., Sirkin, H. L., & Butman, J. (2007). Payback: reaping the rewards of innovation. Harvard Business Press.

Annual report (2015-16), Government of India, Ministry of Micro, Small and Medium Enterprises.

Annual report (2016-17), Government of India, Ministry of Micro, Small and Medium Enterprises.

Annual report, Government of India, Ministry of Micro, Small and Medium Enterprises, 2015-16 CII report, 2011. Innovation: Changing the MSME landscape. Published by Confederation of Indian Industry.

Antonioli, D., & Della Torre, E. (2015). Innovation adoption and training activities in SMEs. The International Journal of Human Resource Management, (ahead-of-print), 1-27.

Archer B (1965)., Systematic Methods for Designers, Council of Industrial Design.

Arroio, A., & Scerri, M. (2010). Comparative Report on the Role of Small and Medium Enterprise in National Innovation Systems of BRICS.

Assarlind, M (2014): “Adoption of quality management in SMEs”. Chalmers University of Technology.

Audretsch, D. B. (2001). Research issues relating to structure, competition, and performance of small technology-based firms. Small business economics, 16(1), 37-51.

AUTO - Economic Times at https://auto.economictimes.indiatimes.com/news/industry/indian-msmes-faces-tough-competition-from-cheap-chinese-products/55469094. Accessed on 28th July 2018

B

Bala Subrahmanya, M. H. (2009). Nature and strategy of product innovations in SMEs: A case study-based comparative perspective of Japan and India. Innovation, 11(1), 104-113.

Bala Subrahmanya, M. H. (2013). Why do only some SMEs achieve external support for better innovation performance: empirical evidence from Bangalore, India. Asian Journal of Technology Innovation, 21(1), 21-33.

Bala Subrahmanya, M.H. (2005), "Small Scale Industry in India Under Globalization: Does solace lie in Technology or Innovation?", International Journal of Management and Enterprise Development, Vol. 2, Issue 1.

Bala Subrahmanya.M H, (2012). Technological innovation in Indian SMEs: an empirical perspective. Published by Indian Institute of Science, Bangalore.

Bartel, C. A., & Garud, R. (2009). The role of narratives in sustaining organizational innovation. Organization science, 20(1), 107-117.

Bell, D. (2010). Framework for Introducing and Implementing Value Methods: A Novel Toolkit for Small and Medium Scale Industries in Developing Nations. International Journal of Basic & Applied Sciences IJBAS, 9(10), 130-146.

Bell, G. G. (2005). Clusters, networks, and firm innovativeness. *Strategic management journal*, *26*(3), 287-295.

Besemer S (1998).: Creative product analysis matrix: testing the model structure and a comparison among products three novel chairs. Creative Res J 11(3):333–346.

Bewoor, A. K., & Pawar, M. S. (2010) 2Professor and Vice-Principal, BMIT, Solapur University, Solapur Maharashtra, India, Journal of *Engineering Research and Studies E-ISSN*, *976*, 7916.

Boer, H., & During, W. E. (2001). Innovation, what innovation? A comparison between product, process and organizational innovation. International Journal of Technology Management, 22(1-3), 83-107.

Boland, R. J., & Collopy, F. (2004). Design matters for management (pp. 3-18). na.

Borja De Mozota, B., Kim, B. Y. (2009) Managing Design as a Core Competency: Lessons from Box, George, and Stephen Jones.: "Designing products that are robust to the environment." Total Quality Management 3.3: 265-282. (1992), Korea. Design Management Review, 20(2) 66–76.

Bossuyt, Patrick, (2012) A comparison of probabilistic unfolding theories for paired comparisons data. Springer Science & Business Media.

Box, G., and Stephen J..: Designing products that are robust to the environment. Total Quality Management 3.3: 265-282. (1992)

Brem A., Voigt K.-I. (2009). Integration market pull and technology push in the corporate front end and innovation management – Insights from the German software industry. In: Technovation, Vol. 29, Issue. 5, pp. 351-367.

Brem, A., & Wolfram, P. (2014). Research and development from the bottom up-introduction of terminologies for new product development in emerging markets. Journal of Innovation and Entrepreneurship, 3(1), 1-22.

Brown, T. (2009). Change by design.

Bruce, M., & Bessant, J. R. (2002). Design in business: Strategic innovation through design. Pearson education.

Buchanan R (1998)., Wicked Problems in Design Thinking, Design Issues, 8.

Bucolo, S. (2011). Continuous Innovation in SMEs: how design innovation shapes business performance through doing more with less. In Proceedings of the 12th International CINet Conference: Continuous Innovation: Doing More with Less.

Buhl H (1960).: Creative engineering design. Iowa State University Press, Ames.

Bullinger A.C. (2008). Innovation and Ontologies – Structuring the Early Stages of Innovation Management, Gabler, Wiesbaden.

C

Cagan, J., & Vogel, C. M. (2002). Creating breakthrough products: Innovation from product planning to program approval. Ft Press.

Calabretta, G. and Montaña J. A (2006) Description of the Design Management Process: Involved Activities and Enabling Conditions. EURAM: The European Academy of Management Annual Conference; Oslo, Norway.

Caloghirou Y., Kastelli I., Tsakanikas A. (2004). Internal capabilities and external knowledge sources: complements or substitutes for innovative performance? In: Technovation, Vol. 24, No. 1, pp. 29-39.

Chakrabarti, Amaresh, and Lucienne Blessing (2016).: "A Review of Theories and Models of Design." Journal of the Indian Institute of Science 95.4: 325-340

Chandy R.K., Tellis G.J. (1998). Organizing for Radical Product Innovation. In: Journal of Marketing Research, Vol. 35, No. 4, pp. 474-487.

Changqing, G., Kezheng, H., & Fei, M (2005).: Comparison of innovation methodologies and TRIZ. The TRIZ Journal, Issue September.

Chaturvedi, M. (1997). New Product Development. Wheeler Publishing. ISBN: 81-85814-92-9

Cho, H. J., & Pucik, V. (2005). Relationship between innovativeness, quality, growth, profitability, and market value. Strategic management journal, 26(6), 555-575.

Chulvi, V., Mulet, E., Chakrabarti, A., Lopez-Mesa, B., & González-Cruz, C (2012).: Comparison of the degree of creativity in the design outcomes using different design methods. Journal of Engineering Design, 23(4), 241-269.

CII report, 2011. Innovation: Changing the MSME landscape. Published by Confederation of Indian Industry.

Clarkson, J. P. (1998). An investigation and review of the knowledge needs of designers in SMEs. The Design Journal, 1(3), 16-29.

Clemmensen, T. Yammiyavar. P (2008). Interaction design & usability from an Indian Perspective.

Coffman, B., & Kaufman, M. (2007). Innovation and transformation: a lifecycle model. Innovation Labs white paper.

Cooper, R. G., & Kleinschmidt, E. J. (1986). An investigation into the new product process: steps, deficiencies, and impact. Journal of product innovation management, 3(2), 71-85.

Cooper R.G. (1994). New Products: The Factors that Drive Success. In: International Marketing Review, Vol. 11, Issue. 1, pp. 60-76.

Cooper R.G. (2011). Winning at New Products: Creating Value Through Innovation, 4th edition, Basic Books, New York, NY.

Cormican, K., & O'Sullivan, D. (2004). Auditing best practice for effective product innovation management. Technovation, 24(10), 819-829.

Cropley, D. H., Kaufman, J. C., & Cropley, A. J. (2011). Measuring creativity for innovation management. Journal of technology management & innovation, 6(3), 13-30.

Cross, N., & Roy, R. (1989). Engineering design methods (Vol. 4). New York: Wiley.

Cross, N. (2008). Engineering design methods: strategies for product design.

OECD, Development. Economic Analysis, & Statistics Division. (2003). OECD Science, Technology and Industry Scoreboard, Canongate US.

D

De Saá-Pérez, P., Díaz-Díaz, N. L., & Luis Ballesteros-Rodriguez, J. (2012). The role of training to innovate in SMEs. Innovation, 14(2), 218-230.

Defeo, Joseph A., and Joseph M. Juran (2010). Juran's Quality Handbook: The Complete Guide to Performance Excellence 6/e. McGraw Hill Professional.

Design Clinic Scheme for MSMEs- http://www.designclinicsmsme.org

Dix, A. (2009). Human-computer interaction. In Encyclopedia of database systems (pp. 1327-1331). Springer US.

Doctoral thesis, Ilipinar, G. (2014). The great age of design: from design thinking to mental midwifery and to design's impact on brands.

Drucker, P. (2014). Innovation and entrepreneurship. Routledge.

Drucker, P. F. (2002). The discipline of innovation. Harvard business review, 80, 95-104.

Dutta, S., Geiger, T., & Lanvin, B. (2015) The global information technology report. In World Economic Forum.

Dym, C. L., Wood, W. H., & Scott, M. J. (2002). Rank ordering engineering designs: pairwise comparison charts and Borda counts. Research in Engineering Design, 13(4), 236-242.

E

Eden, L., Levitas, E., & Martinez, R. J. (1997). The production, transfer and spillover of technology: comparing large and small multinationals as technology producers. Small Business Economics, 9(1), 53-66.

El-Sharkawy, S., & Schmid, K (2011).: A heuristic approach for supporting product innovation in requirements engineering: a controlled experiment. In Requirements Engineering: Foundation for Software Quality (pp. 78-93). Springer Berlin Heidelberg

Empowering the Indian SME Economy Evolution through Global Partnership, SME connect 2015.

European Commission (1995). Green Paper on Innovation, COM (95) 688, December, Brussels

Eveleens, C. (2010). Innovation management; a literature review of innovation process models and their implications. Science, 800(2010), 900.

F

Flores, M., Boër, C., Huber, C., Plüss, A., Schoch, R., & Pouly, M. (2009). Universities as key enablers to develop new collaborative environments for innovation: successful experiences from Switzerland and India. International Journal of Production Research, 47(17), 4935-4953.

Fogler, H. Scott, Steven E. LeBlanc, and Benjamin Rizzo (1995).: Strategies for creative problem solving. Englewood Cliffs, NJ: PTR Prentice Hall.

Franz, Jill M. (2000) An interpretative-contextual framework for research in and through design. In *Doctoral Education in Design: Foundations for the Future*, 8-12 July, 2000, La Clusaz, France.

G

Gamal, D., Salah, T., & Elrayyes, E. N. (2011). How to measure organization Innovativeness Technology Innovation and Entrepreneurship Center.

Gandhi, O. P., & Agrawal, V. P. (1992). FMEA—A diagraph and matrix approach. Reliability Engineering & System Safety, 35(2), 147-158.

Garcia R. and Calantone R (2002).: A critical look at technological innovation typology and innovativeness terminology: a literature review. The Journal of Product Innovation Management, 19, pp110 -132.

Ghoshal, M. (2017, Jan) Trade Performance of India and China in Micro, Small and Medium Enterprises Sector- A Case Study, in XVIII Annual International Conference Proceedings ISBN no. 978-81-923211-9-6

Gittelman, M. (2008). A note on the value of patents as indicators of innovation: Implications for management research. The academy of management perspectives, 22(3), 21-27.

Goldenberg, J., & Mazursky, D. (2002). Creativity in product innovation. Cambridge University Press.

Goldschmidt, G. (1996). The designer as a team of one in N. Cross, HHCM Christiaans & K. Dorst (Eds.), Analyzing design activity (pp. 65-91).

Goldschmidt, G. (2014). Linkography: unfolding the design process. Mit Press.

Goldsmith, R. E. (1990). The validity of a scale to measure global innovativeness. Journal of Applied Business Research, 7(2), 89-97.

Grant-Thornton –FICCI Report - http://ficci.in/spdocument/20249/Grant-Thornton-FICCI-report.pdf accessed on 28th July 2018.

Grover, S., Agrawal, V. P., & Khan, I. A. (2004). A digraph approach to TQM evaluation of an industry. International Journal of Production Research, 42(19), 4031-4053.

Growth drivers for tomorrow,' SME sector driving India's growth story' by TOI 10-3-2015.

Gupta, A. K. (2009). Innovations for reviving small-scale industries. Indian Institute of Management.

H

Hansen M.T., Birkinshaw J. (2007). The Innovation Value Chain. In: Harvard Business Review, Vol. 85, Iss. 6, pp. 121-130.

Hatchuel, A., & Weil, B. (2003). A new approach of innovative Design: an introduction to CK theory. In DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm.

Hauschildt J., Salomo S. (2011). Innovations management, 5th edition, Vahlen, München.

Heskett, J. (2005). Design: A very short introduction (Vol. 136). Oxford University Press.

Hillemane, B. S. M. (2012). Technological Innovation in Indian SMEs: Need, Status and Policy Imperatives. Current Opinion in Creativity, Innovation and Entrepreneurship, 1(2).

Hobday, M., Boddington, A., Grantham, A. (2012) An Innovation Perspective on Design: Part 2. Design Issues, (28) 18–29.

Hogan, S. J., & Coote, L. V. (2014). Organizational culture, innovation, and performance: A test of Schein's model. Journal of Business Research, 67(8), 1609-1621.

Honey bee http://www.sristi.org/cms/en/our_network Society for Research and Initiatives for Sustainable Technologies and Institutions.

Howard, T. J., Culley, S. J., & Dekoninck, E. (2008). Describing the creative design process by the integration of engineering design and cognitive psychology literature. Design studies, 29(2), 160-180.

http://creatingminds.org/tools/scamper.htm; visited on 19-4-16

http://deepcentre.com/blog/how-are-the-brics-countries-doing-in-rd Accessed on 10-01-2018

http://designtechniques.wikispaces.com/Pahl+and+Beitz accessed on 20/04/16

http://europa.eu/documents/comm/green_papers/pdf/com95_688_en.pdf, last accessed on 30/09/2012.

http://iitg.ac.in/uelab/about.html

http://innovationexcellence.com/blog/2010/08/22/25-definitions-of-innovation/ as ray meads, and Robert Bastarache

http://insideiim.com/wp-content/10/Market-share-distribution-in-SMB.png Adopted from Source, (Visited on 20-3-2016)

http://smallbusiness.chron.com/calculate-total-manufacturing-cost-accounting-39694.html accessed on 11-07-2016

http://ww1w.liquisearch.com/heuristic_evaluation (visited on 20-04-16) Nielson’s

http://www.creativityatwork.com/design-thinking-strategy-for-innovation/ 23-4-16

http://www.dmi.org/news/247277/Lean-Startup-Design-Thinking--Open-Innovation-for-the-Enterprise.htm Janqua interview, 13-10-2017

http://www.knowdo.org/knowledge/34-design-thinking david burney 2007, 13-10-2017

http://www.southeast-asia.atkearney.com/innovation/case-studies, last accessed on 23/03/2017

https://evoma.com/business-centre/sme-sector-in-india-statistics-trends-reports/

https://www.iso.org/standard/31176.html ISO (Visited on 26-10-2017)

https://www.mindtools.com/pages/article/newPPM_89.htm (visited on 19-4-16) https://www.nibusinessinfo.co.uk/content/design-audit accessed on 31 -7 -18.

https://www.symphony-solutions.eu/service/uiux-design-and-development/design-audit/ accessed on 31 -7 -18.

Hu, B. (2014). Linking business models with technological innovation performance through organizational learning. European Management Journal, 32(4), 587-595.

Hungund, S. S. (2014). Open Innovation practices and challenges among Indian SMEs (Doctoral dissertation, National Institute of Technology, Karnataka Surathkal).

I

Ivanov, C. I., & Avasilcăi, S. (2014). Measuring the performance of innovation processes: A Balanced Scorecard perspective. Procedia-Social and Behavioral Sciences, 109, 1190-1193.

J

J.Nielson (1992), The usability engineering life cycle, IEEE computers, 25(3)12-22.

Jacobs, D., & Snijders, H. (2008). Innovation routine: how managers can support repeated innovation. Stitching Management Studies.

Jaruzelski, B., Dehoff, K., & Bordia, R. (2005). Money Isn't Everything Lavish R&D budgets don't guarantee success. The Booz Allen Hamilton Global Innovation 1000 tracked the world's heaviest innovation spenders against common measures of performance and success. Strategy and Business, 41, 54.

Javalgi, R. R. G., & Todd, P. R. (2011). Entrepreneurial orientation, management commitment, and human capital: The internationalization of SMEs in India. Journal of Business Research, 64(9), 1004-1010.

Jaworski, B. J., & Kohli, A. K. (1993). Market orientation: antecedents and consequences. The Journal of marketing, 53-70.

Jiménez-Jiménez, D., & Sanz-Valle, R. (2011). Innovation, organizational learning, and performance. Journal of business research, 64(4), 408-417.

Johannessen, J.A. (2008), Organizational innovation as part of knowledge management, International Journal of Information Management, 28(5), pp.403-412.

Justel, D., Vidal, R., Arriaga, E., Franco, V., & Val-Jauregi, E (2007).: Evaluation method for selecting innovative product concepts with greater potential marketing success. In Proceedings of 16th international conference on engineering design, Paris, France.

K

K. T. Ulrich and S. D. Eppineger (1995), Product design and development, McGraw-Hill, pp. 168, 169

Kan, W. T., & Gero, J. S. (2004, November). A method to analyze team design activities. In Proceedings of 38th ANZAScA Conference Proceedings (pp. 111-117).

Kano N., Seraku N., Takahashi F. and Tsuji S (1996).: Attractive quality and must-be quality. In The best on quality. Book Series of the International Academy for Quality. Milwaukee: ASQC Quality Press, volume7.

Kaplan, R. S., & Norton, D. P. (1996). The balanced scorecard: translating strategy into action. Harvard Business Press.

Katre, D., Orngreen, R., Yammiyavar, P., & Clemmensen, T. (Eds.). (2010). Human Work Interaction Design: Usability in Social, Cultural and Organizational Contexts: Second IFIP WG 13.6 Conference, HWID 2009, Pune, India, October 7-8, 2009, Revised Selected Papers (Vol. 316). Springer.

Kearney, A. T. (2008). Innovation Management: strategies for success and leadership. Chicago: AT Kearney.

Kim, D. Y., Kumar, V., & Kumar, U. (2012). Relationship between quality management practices and innovation. Journal of Operations Management, 30(4), 295-315.

Kotler, P., and Rath, G. A. (1984). Design: a powerful but neglected strategic tool. Journal of business strategy, 5(2), 16-21.

Krishnaswamy, K. N., Mathirajan, M., & Subrahmanya, M. B. (2014). Technological innovations and its influence on the growth of auto component SMEs of Bangalore: A case study approach. Technology in Society, 38, 18-31.

Kumar, R., K. Singh, R., & Shankar, R. (2014). Strategy development by Indian SMEs for improving coordination in supply chain: an empirical study. Competitiveness Review, 24(5), 414-432.

L

Laforet, S. (2008). Size, strategic, and market orientation affects on innovation. Journal of Business Research, 61(7), 753-764.

Lee, S., Park, G., Yoon, B., & Park, J. (2010). Open innovation in SMEs—An intermediated network model. Research policy, 39(2), 290-300.

Lottersberger, A. (2012). Design, innovation and competitiveness in the textile industry. Upstream design driven innovation.

Luís Ramos da Silva, F., Lucchesi Cavalca, K., & Giuseppe Dedini, F. (2004). Combined application of QFD and VA tools in the product design process. International Journal of Quality & Reliability Management, 21(2), 231-252.

Lutters, E., van Houten, F. J., Bernard, A., Mermoz, E., & Schutte, C. S (2004).:" Tools and techniques for product design". CIRP Annals-Manufacturing Technology, 63(2), 607-630.

M

M, H, Bala Subrahmanya., M, Mathirajan., K, N, Krishnaswamy (2010).: "Importance of technological innovation for SME growth: Evidence from India". Published by United Nations University Management, (865) 389–393.

Mumford, M. D., & Licuanan, B. (2004). Leading for innovation: Conclusions, issues, and directions. The leadership quarterly, 15(1), 163-171.

Mathur, A., Mittal, M. L., & Dangayach, G. S. (2012). Improving productivity in Indian SMEs. Production Planning & Control, 23(10-11), 754-768.

Matthews, J. H., & Bucolo, S. (2011). Continuous Innovation in SMEs: how design innovation shapes business performance through doing more with less. In Proceedings of the 12th International CINet Conference: Continuous Innovation: Doing More with Less.

Maylor, H (1997).: Concurrent new product development: an empirical assessment. International Journal of Operations & Production Management, 17(12), 1196-1214

McCraw, T. K. (2009). Prophet of innovation. Harvard university press.

Meads. Ray, (2003) Talks on innovation across academic, business and government events, 'Critical issues in corporate and small business entrepreneurship US.

Measuring usability http://www.measuringu.com/blog/he-cw.php (visited on 19-4-16)Weinschenk and Barker

Michelle Gittelman (2006). Academy of Management Perspectives Vol. 22, No. 3 (Aug., 2008), pp. 21-27 Kearney, A. T. House of innovation. www. improve-innovation. eu.

Milbergs, E., & Vonortas, N. (2004). Innovation metrics: measurement to insight. Center for Accelerating Innovation and George Washington University, National Innovation Initiative 21st Century Working Group, 22.

Modi, S. (2014). Problems and Prospects of Indian Small Scale Industries. Business Commission. An International Open Free Access, Peer Reviewed Research Journal, 3(3), 201-206.

Morris, R. (2009). The fundamentals of product design. AVA Publishing. ISBN 2-940373-17-5.

Mortensen, P. S., & Bloch, C. W. (2005). Oslo Manual-Guidelines for Collecting and Interpreting Innovation Data: Proposed Guidelines for Collecting and Interpreting Innovation Data. Organization for Economic

Mozota, D., Borja, B., & Kim, B. Y. (2009). Managing design as a core competency: Lessons from Korea. Design Management Review, 20(2), 66-76.

MSMEs IN INDIA.: It's Growth and Prospects Volume 3, Issue 8 (August,) Online ISSN-2277-1166, 2014

MSMEs: http://www.dcmsme.gov.in/ssiindia/defination_msme.htm

Mulgan, G., & Albury, D. (2003). Innovation in the public sector. Strategy Unit, Cabinet Office, 1-40.

Muller, R. M., & Thoring, K (2012).: Design thinking vs. lean startup: A comparison of two user-driven innovation strategies. LEADING THROUGH DESIGN, 151.

Murthy, D. P., Rausand, M., & Osteras, T (2008).: Product reliability: specification and performance. Springer Science & Business Media.

N

Naiman, Linda (2013). "Creativity at work.".

Narver, J. C., Slater, S. F., & Tietje, B. (1998). Creating a market orientation. *Journal of market-focused management*, *2*(3), 241-255.

Naville Stanton (ed.) (1998)., Human factors in consumer products, Taylor & Francis, pp. 9–10

Neumann, M. (2013). Ideation reference process model for the early phase of innovation (Doctoral dissertation, Université Grenoble Alpes).

Nielsen, J. (2005). Ten usability heuristics.

Nijssen, E. J., & Frambach, R. T (2000).: Determinants of the adoption of new product development tools by industrial firms. Industrial Marketing Management, 29(2), 121-131.

Noble, C. H. (2011). On elevating strategic design research. Journal of Product Innovation Management, 28(3), 389-393.

Nooteboom, B. (2000). Learning and innovation in organizations and economies. OUP Oxford.

Norman, D. (2013). The design of everyday things: Revised and expanded edition. Basic Books (AZ).

Norman, D. A., & Verganti, R. (2014). Incremental and Radical Innovation: Design Research vs. Technology and Meaning Change, 30(1).

O

Odedairo, B. O., & Bell, D. (2010). Framework for Introducing and Implementing Value Methods: A Novel Toolkit for Small and Medium Scale Industries in Developing Nations. International Journal of Basic & Applied Sciences IJBAS, 9(10), 130-146.

Oman, S. K., Tumer, I. Y., Wood, K., & Seepersad, C (2013).: A comparison of creativity and innovation metrics and sample validation through in-class design projects. Research in Engineering Design, 24(1), 65-92.

Otto, Kevin N., and Kristin L.Wood. (1998): "Product evolution: a reverse engineering and redesign methodology." Research in Engineering Design 10.4: 226-243.

P

Pahl, G., & Beitz, W. (2013). Engineering design: a systematic approach. Springer Science & Business Media.

Panizzolo, R., Garengo, P., Sharma, M. K., & Gore, A. (2012). Lean manufacturing in developing countries: evidence from Indian SMEs. Production Planning & Control, 23(10-11), 769-788.

Pawan, Sikka., (1998). Technological innovations by SMEs in India. Technovision 19, 317 – 321

Petrick, I. J., & Echols, A. E. (2004). Technology road mapping in review: A tool for making sustainable new product development decisions. Technological Forecasting and Social Change, 71(1), 81-100.

Phaal, R., Farrukh, C. J., & Probert, D. R. (2004). Technology road mapping—a planning framework for evolution and revolution. Technological forecasting and social change, 71(1), 5-26.

Polanyi, M. (2009). The tacit dimension. University of Chicago press.

Pugh S (1996).: Creating innovative products using total design. Addison-Wesley Publishing Company, Reading

R

Rao, B. C. (2013). How disruptive is frugal? Technology in Society, 35(1), 65-73.

Rao, R. V. (2006). A material selection model using graph theory and matrix approach. Materials Science and Engineering: A, 431(1), 248-255.

Rao, R. V., & Gandhi, O. P. (2002). Digraph and matrix methods for the machinability evaluation of work materials. International Journal of Machine Tools and Manufacture, 42(3), 321-330.

Report by Chamber of Indian Micro Small and medium enterprises, 2016.

Report of The Working Group On Science & Technology for Small & Medium Scale Enterprises (SMEs) For The Eleventh Five Year Plan (2007-2012)

Reverse innovation 2.0: More MNCs take India’s frugal engineering to global TOI 23-7-2015

Riedl C., May N., Finzen J., Stathel S., Kaufman V., Krcmar H. (2009). An Idea Ontology for Innovation Management. In: International Journal on Semantic Web and Information Systems, Vol. 4, No. 4, pp. 1-18.

Ries, E (2011).: The lean startup: how today's entrepreneurs use continuous innovation to create radically successful businesses. New York: Crown Business.

Robert Bastarache http://innovationexcellence.com/blog/2010/08/22/25-definitions-of-innovation/ visited on 19 Feb 2016)

Rodgers, P. A., & Clarkson, J. P. (1998). An investigation and review of the knowledge needs of designers in SMEs. The Design Journal, 1(3), 16-29.

Rodriguez, D., (2007). MSI Conference: Design Meets Marketing: Service Innovation by Design (editors: Gursel Ilipinar, Gaia Rubera, and Sarah J.S. Wilner, 2008, 08-300)

Rodriguez, m. M., Casper, g. and Brennan, p. F. (2007). 'Patient-Centered Design: The Potential of User-Centered Design in Personal Health Records'. Journal of AHIMA, 4(78), 44-45.

Rogers E.M. (2003). Diffusion of innovations, 5th edition, Free Press, New York.

Rogers, E. M. (1962). Diffusion of innovations. New York: Free Press of Glencoe.

Rogers, E. M. (2010). Diffusion of innovations. Simon and Schuster.

Rogers, Y., Sharp, H., & Preece, J. (2011). Interaction design: beyond human-computer interaction. John Wiley & Sons.

Roozenburg, N. F., & Eekels, J. (1995): Product design: fundamentals and methods (Vol. 2). Chichester: Wiley New York.

Rothwell, R. (1994). Towards the fifth-generation innovation process. International marketing review, 11(1), 7-31.

Rural Technology park promotes indigenous technologies. THE HINDU 5-2-2015

S

Sarkar P, Chakrabarti (2008).: A The effect of representation of triggers on design outcomes. Artif Intell Eng Des Anal Manuf 22(2):101–116

Sato, Y., & Kaufman, J. J. (2005). Value analysis tear-down: a new process for product development and innovation. Industrial Press Inc.

Sawhney, M., Wolcott, R. C., & Arroniz, I. (2007). The 12 different ways for companies to innovate. IEEE Engineering Management Review, 35(1), 45-52.

Schumpeter, J. A. (2017). Theory of economic development. Routledge.

Schumpeter J.A. (1982). The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle, with a New Introduction by John E. Elliott, Reprint, originally published: Cambridge, Mass.: Harvard University Press, 1934, Transaction Publishers, New Brunswick, New Jersey.

Scozzi, B., Garavelli, C., & Crowston, K. (2005). Methods for modeling and supporting innovation processes in SMEs. European Journal of Innovation Management, 8(1), 120-137.

Sethi, R., (2014). Small enterprises as big business. The Hindu - National Newspaper, December 25.

Shackel.B. (1981), The concept of usability, Proc.IBM Software and Information Usability symp, NY,pp.1-30September 15-18.

Simmonds, K. (1986). Marketing as Innovation the eighth paradigm. Journal of Management Studies, 23(5), 479-500.

Simmonds, K., & Smith, H. (1968). The first export order: a marketing innovation. European Journal of Marketing, 2(2), 93-100.

Simon H (1969)., The Science of the Artificial, MIT Press.

Singh, B., Matthews, J., Mullineux, G., & Medland, T. (2009). Product development in manufacturing SMES: Current state, challenges and relevant supportive techniques. In DS 58-6: Proceedings of ICED 09, the 17th International Conference on Engineering Design, Vol. 6, Design Methods and Tools (pt. 2), Palo Alto, CA, USA.

Singh, R., & Sekhon, G. S. (1996). A computerized diagraph and matrix approach for evaluation of metal stamping layouts. Journal of Materials Processing Technology, 59(4), 285-292.

Skill development in the sector of MSME, (2015-16) Published by Small Industries Development Bank of India. Lucknow, India

SME knowledge series, creating values for SME's concepts and strategies in Indian context I, Dr. S. P. Agarwal, Prof. & Head, CITT, IIFT, New Delhi and Ms. Dolly Bhasin is the CEO of a knowledge enterprise – SPH, 2006.

SME TIMES, 2015, SME policy: What China is doing and we're not – sourced from http://www.smetimes.in/smetimes/editorial/2015/Jan/27/sme-policy-what-china-doing-and-we-are-not29921.html accessed on 28th July 2018.

Sok, P., & O'Cass, A. (2015). Examining the new product innovation–performance relationship: Optimizing the role of individual-level creativity and attention-to-detail. Industrial Marketing Management, 47, 156-165.

Sokovic, M., Jovanovic, J., Krivokapic, Z., & Vujovic, A (2009).: Basic quality tools in continuous improvement process. Strojniski vestnik-Journal of Mechanical Engineering, 55(5), 333-341.

Sonja, Radas., Ljilajana, Bozic., (2009). The antecedents of SME innovativeness in an emerging transition economy. Technovision 29 (2009), 438 – 450.

Strategic Development of MSMEs, (2016), occasional paper no. 153, Export-Import Bank of India, India.

Subrahmanya, M. B. (2005). Pattern of technological innovations in small enterprises: a comparative perspective of Bangalore (India) and Northeast England (UK). Technovation, 25(3), 269-280.

T

Tague, N. R. (2005): The quality toolbox (Vol. 600). Milwaukee, WI: ASQ Quality Press.

Tether, B. S. (1998). Small and large firms: sources of unequal innovations? Research policy, 27(7), 725-745.

THE ECONOMIC TIMES, Why India is lagging in Disruptive Innovation, Dated:23-07-2015

Thia, C. W., Chai, K. H., Bauly, J., & Xin, Y (2005).:" An exploratory study of the use of quality tools and techniques in product development". The TQM Magazine, 17(5), 406-424.

Thom N. (1980). Grundlagen des betrieblichen Innovationsmanagements, 2nd edition, Peter Hanstein Verlag, Königstein/Taunus.

Tidd, J. (Ed.). (2006). From knowledge management to strategic competence: measuring technological, market and organisational innovation (Vol. 3). World Scientific.

Tidd, J., Bessant, J. R., & Pavitt, K. (1997). Managing innovation: integrating technological, market and organizational change (Vol. 4). Chichester: Wiley.

Tidd, J., Bessant, J., & Pavitt, K. (2005). Managing innovation integrating technological, market and organizational change. John Wiley and Sons Ltd.

Timothy Whitehead, Dr Mark Evans, Guy Bingham, (2014). A framework for design and assessment of products in developing countries. In Design Research Conference 2014 - Umea, Sweden.

Todd, P. R., Javalgi (2011). Entrepreneurial orientation, management commitment, and human capital: The internationalization of SMEs in India. Journal of Business Research, 64(9), 1004-1010.

Tom Kelly (2003), The art of innovation, Profile Books, pp. 6–7, 37–41.

Trott, P. (2008). Innovation management and new product development. Pearson education.

U

Ullman D (2010).: The mechanical design process. McGraw-Hill Science/Engineering/Math, New York.

Ullman, D. G. (2002). The mechanical design process. McGraw-Hill Science/Engineering/Math.

Ulrich K, Eppinger S (2000).: Product design and development. McGraw-Hill, Boston.

Ulrich, K. T. (2003). Product design and development. Tata McGraw-Hill Education.

Usability http://www.merriam-webster.com/dictionary/usability

V

Van de Ven, A. H., & Poole, M. S. (1990). Methods for studying innovation development in the Minnesota Innovation Research Program. Organization science, 1(3), 313-335.

Van de Ven, A. H., Polley, D. E., Garud, R., & Venkataraman, S. (1999). The innovation journey.

Van de Vrande, V., De Jong, J. P., Vanhaverbeke, W., & De Rochemont, M. (2009). Open innovation in SMEs: Trends, motives and management challenges. Technovation, 29(6-7), 423-437.

Van der Lugt, R. (2001). Sketching in design idea generation meetings. PhD Dissertation, 2001, Faculty of Industrial Design: Delft University of Technology.

VanGundy, A. B. (1988). Techniques of structured problem solving. Springer.

Venkatasamy, R., & Agrawal, V. P. (1997). A digraph approach to quality evaluation of an automotive vehicle. Quality Engineering, 9(3), 405-417.

Verganti, R. (2008). Design, meanings, and radical innovation: A metamodel and a research agenda. Journal of product innovation management, 25(5), 436-456.

Verganti, R. (2009). Design driven innovation: changing the rules of competition by radically innovating what things mean. Harvard Business Press.

Verganti, R. (2009). Design-driven innovation. Boston, MA.

Verhees, F. J., & Meulenberg, M. T. (2004). Market orientation, innovativeness, product innovation, and performance in small firms. *Journal of small business management*, *42*(2), 134-154.

Verloop, J. (2004) Insight in Innovation: Managing innovation by understanding the Laws of Innovation. Elsevier Science.

Veryzer, R. W., & Borja de Mozota, B. (2005). The impact of user-oriented design on new product development: An examination of fundamental relationships. Journal of product innovation management, 22(2), 128-143.

Vives X. (2008). Innovation and Competitive Pressure. In: The Journal of Industrial Economics, Vol. 56, Iss. 3, pp. 419-469.

W

Wunsch-Vincent, S., Lanvin, B., & Dutta, S (2015).: "The Global Innovation Index 2015": Effective Innovation Policies for Development. eSocialSciences.

Y

Yammiyavar, P (2004). Product proximity factor-A human interaction based model for optimizing parameters within a product's design space, HWWE.

Yammiyavar, P. (2010). Status of HCI and usability research in Indian educational institutions. In Human Work Interaction Design: Usability in Social, Cultural and Organizational Contexts (pp. 21-27). Springer, Berlin, Heidelberg.

Yammiyavar, P. (2005). Usability heuristics and their role in designing vehicles-A case study of an electric-hybrid vehicle body design. Journal of the Indian Institute of Science, 85(2), 67-82.

Yammiyavar, P. (2005). Emotion as a Construct in HCI. In Research Symposium (Vol. 8).

Yammiyavar P (1993), Industrial design of electronic equipment, IMPACT, Center for electronics design and technology, Indian institute of Science, Bangalore, pp. 18-23

Yang, F. (2015). A New Process for Creating Design Briefs to Improve Design Innovations in Home Health Care (Doctoral dissertation, University of the Arts London and Falmouth University).

Yeh, T. M., Pai, F. Y., & Yang, C. C (2010).: Performance improvement in new product development with effective tools and techniques adoption for high-tech industries. Quality & Quantity, 44(1), 131-152.